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A Case of Korea**

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Essays on Uncertainty, Asset Prices and Monetary Policy: A Case of Korea

PAUL SANG-HO YI

A thesis submitted for the degree of Doctor of Philosophy

**University of Bath
Department of Economics**

October 2013

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Dedication

For my parents; my brother, Sang-Won;
and my wife, Gwi-Yeon KIM

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Completing the thesis as a part-time researcher proved to be a long and exhausting journey in my life, ending in victory over my inner self.

My sincere hope is that it will prove to be a useful contribution to the body of knowledge in the field. If there remain any errors or inadequacies in this work, the responsibility is my own.

Abstract

In Korea, an inflation targeting (IT) regime was adopted in the aftermath of the Korean currency crisis of 1997–1998. At that time, the Bank of Korea (BOK) shifted the instrument of monetary policy from monetary aggregates to interest rates. Recently, central bank policymakers have confronted more uncertainties than ever before when deciding their policy interest rates. In this monetary policy environment, it is worth exploring whether the BOK has kept a conservative posture in moving the Korean call rate target, the equivalent of the US Federal Funds rate target since the implementation of an interest rate-oriented monetary policy. Together with this, the global financial crisis (GFC) of 2007–2009 provoked by the US sub-prime mortgage market recalls the following question: should central banks pre-emptively react to a sharp increase in asset prices? Historical episodes indicate that boom-bust cycles in asset prices, in particular, house prices, can be damaging to the economy. In Korea, house prices have been evolving under uncertainties, and in the process house-price bubbles have been formed. Therefore, in recent years, central bankers and academia in Korea have paid great attention to fluctuations in asset prices.

In this context, the aims of this thesis are: (i) to set up theoretical and empirical models of monetary policy under uncertainty; (ii) to examine the effect of uncertainty on the operation of monetary policy since the adoption of interest rate-oriented policy; and (iii) to investigate whether gradual adjustment in policy rates can be explained by uncertainty in Korea. Another important aim is (iv) to examine whether house-price fluctuations

should be taken into account in formulating monetary policy.

The main findings of this thesis are summarised as follows. Firstly, as in advanced countries, the four stylised facts regarding the policy interest rate path are found in Korea: infrequent changes in policy rates; successive changes in the same direction; asymmetric adjustments in terms of the size of interest-rate changes for continuation and reversal periods; and a long pause before reversals in policy rates. These patterns of policy rates (*i.e.*, interest-rate smoothing) characterised the central bank's reaction to inflation and the output gap as being less aggressive than the optimising central bank behavior would predict (Chapter 3).

Secondly, uncertainty may provide a rationale for a smoother path of the policy interest rate in Korea. In particular, since the introduction of the interest rate-oriented monetary policy, the *actual* call money rates have shown to be similar to the *optimal* rate path under parameter uncertainty. Gradual movements in the policy rates do not necessarily indicate that the central bank has an interest-rate smoothing incentive. Uncertainty about the dynamic structure of the economy, which is dubbed 'parameter uncertainty', could account for a considerable portion of the observed gradual movements in policy interest rates (Chapter 4).

Thirdly, it is found that the greater the output-gap uncertainty, the smaller the output-gap response coefficients in the optimal policy rules, and in a similar vein, the greater inflation uncertainty, the smaller the inflation response coefficients. The optimal policy rules derived by using data without errors showed the large size of the output-gap and inflation response coefficients. This finding confirms that data uncertainty can be one of

the sources explaining the reasons why monetary policymakers react less aggressively in setting their interest rate instrument (Chapter 5).

Finally, we found that house prices conveyed some useful information on conditions such as possible financial instability and future inflation in Korea, and the house-price shock differed from other shocks to the macroeconomy in that it had persistent impacts on the economy, consequently provoking much larger economic volatility. Empirical simulations showed that the central bank could reduce its loss values in terms of economic volatility, resulting in promoting overall economic stability when it responds more directly to fluctuations in house prices. This finding provides the reason why the central bank should give more attention to house-price fluctuations when conducting monetary policy (Chapter 6).

List of Abbreviations

AD	Aggregate Demand
ADF	Augmented Dickey-Fuller Test
AIC	Akaike Information Criterion
ARIMA	Auto-Regressive Integrated Moving Average
AS	Aggregate Supply
BCP	Brainard Conservatism Principle
BIS	Bank for International Settlements
BOK	The Bank of Korea
bps	basis points
CEP	Certainty Equivalence Principle
CPI	Consumer Price Index
DISC	Dynamic IS Curve
DSGE	Dynamic Stochastic General Equilibrium
EC	The European Community
ECB	The European Central Bank
ECOS	The BOK Economic Statistic Database System
EMEs	Emerging Market Economies
GDP	Gross Domestic Product
GFC	Global Financial Crisis
GMM	Generalised Method of Moments
HP filter	Hodrick-Prescott filter
IMF	The International Monetary Fund
IT	Inflation Targeting
KPSS	Kwiatkowski, Peter C.B. Phillips, Peter Schmidt and Yongcheol Shin Test
MPC	Monetary Policy Committee
MSE	Mean Squared Error
NK	New Keynesian
NKPC	New Keynesian Phillips Curve
OLS	Ordinary Least Square
PCE	Personal Consumption Expenditures
PP	Phillips-Perron Test
QE	Quantitative Easing
SC	Schwarz Criterion
SVAR	a Structural VAR
VAR	Vector Auto-Regressive

Chapter 1

Introduction: Motivations, Objectives and Thesis Structure

1.1 Background

Since the early 1990s, central banks in many countries have committed themselves to an explicit inflation targeting (IT) regime for their monetary policy framework. With the adoption of an IT regime, central banks started using the policy interest rate (or the key policy rate) as their main instrument to signal their monetary policy stances, instead of monetary aggregates such as M2 or M3.

Under this interest rate-oriented monetary policy framework, central banks are required to make decisions on the size, timing and speed of adjustment of policy interest rates as well as judgement as to whether to change their policy stance. Therefore, central banks' capacity to adjust their key policy rate pre-emptively has come to be regarded as more important than ever before. In these circumstances, inflation-targeting central banks

are required to assess the present and future economic conditions. Despite the development of forecasting techniques, the actual performance of macroeconomic variables such as inflation rate and GDP growth rate have often shown a large difference from the central banks' forecasts, which could bedevil price stability and economic stability that are the important objectives of central banks' monetary policy.

These days, uncertainty is a crucial feature as well as a noticeable characteristic appearing in the process of actual monetary policy-making. Central banks without exception must navigate through evolving uncertainty when formulating and conducting monetary policy. Uncertainty arises in many forms and from various sources including imperfect knowledge about the ever-changing economy, and from unexpected internal or external shocks. Good examples of the last sources are the 1997–1998 Korean currency crisis and the financial market turmoil triggered by delinquencies in the US sub-prime mortgages of 2007–2009.

Accordingly, it has become substantially important to know that central banks should take into consideration uncertainty arising from various matters related to the evolving economic situations when setting their key policy rate. In the following sections, first of all, diverse sources of uncertainty faced by central banks, which are the starting point for this research, will be discussed. In turn, research questions and objectives, and contributions will be presented sequentially.

1.2 Sources of Uncertainty Confronting Central Banks

Uncertainty, which has been shown to have significant impacts on various types of economic decisions, also is likely to affect central banks' decision-making. As

Greenspan (2003) pointed out, uncertainty is not only an important feature of the monetary policy landscape, but also a salient characteristic of that landscape. With few exceptions, central banks face uncertainty and must implement monetary policy under such circumstances. Uncertainty affecting the setting and conduct of monetary policy arises from various sources. In this section, these sources of uncertainty will be discussed in further detail.

First of all, it may be difficult for central bank policymakers to identify with precision the sources and properties, the degree and persistence of exogenous economic disturbances (*e.g.*, overseas shocks such as the global surge in oil or food prices; a rapid rise and sudden decline in asset prices). They will only be known to central banks and the general public after a considerable time-lag. At the time when the economic shocks occur, it may be very hard to appreciate correctly whether the shocks originate from domestic or foreign sources, are temporary or long-lasting, and are derived from the demand or supply side of the economy, or both. Furthermore, it is not easy to identify precisely the degree and impact of such shocks upon the economy.

Second, central bankers need to assess the current state of the overall economy including asset market conditions when they adjust their policy instruments. But, this is not easy because, unlike market data series such as nominal interest rates and exchange rates, which are available on a daily basis without a slight revision, some of the key macroeconomic variables (which are generally aggregate indicators) such as real gross domestic product (GDP) and the consumer price index (CPI), are only available with a lag and a longer frequency. And, even the actual data series, which can be obtained at the time of policy decision-making, are also likely to be measured with great error. In the

real world, specifically, central banks often experience challenges in assessing the level of asset prices and judging whether there are bubbles in them. Given such environments, prior to setting their interest rate instrument, the policymakers need the best possible forecasts of key variables for the design and conduct of monetary policy.

Third, even with accurate data, in reality, the monetary authorities do not know accurately how the economy works. Over the past five decades, understanding about the macroeconomy has been considerably deepened due to significant developments in economic theory and analytical methods. However, there remain highly important issues subject to contentious dispute (Poole, 1998). For instance, how central banks' policy instruments influence inflation and real economic activities (*i.e.*, the transmission mechanism of monetary policy actions into the economy), to what extent it has an influence on the real economy in the short-run (*i.e.*, the slope of Phillips curve) and whether the short-run interest rate adjustments can cut down excessive liquidity (*i.e.*, trade-offs between interest rate rules and monetary aggregate targets) etc., are all the subject of lively debate.

Central bankers usually rely on econometric models to understand how the economy responds when simulated in certain ways, and to create forecasts of key macroeconomic variables. These econometric models contain the parameters governing the interactions that occur within the models. Central bankers can use statistical techniques to obtain estimates of these parameters. Nevertheless, their true values remain uncertain. In other words, the size of parameters may be uncertain. Further, some parameters vary over time. Accordingly, these factors result in uncertainty for policy decision-makers. In this regard, for example, the effect of interest-rate adjustment in curbing asset prices is highly uncertain and can be, in an unexpected direction, transmitted to the overall economy as

well as a particular class of asset market.

Finally, one possible source of the difficulties faced by policymakers is uncertainty as to the correct model of the economy. Our knowledge about the ever-changing structure of the economy is inevitably imperfect. The theoretical and empirical models help monetary policymakers to understand the time lags in, and the ultimate impacts of, monetary policy on the real economic activity, and to cope with various challenges in the formulation of monetary policy.

In reality, however, there is no consensus on the appropriate specification of a model suitable for the analysis of policy issues. Any economic model is just an approximation of a complex reality. Even if policymakers set up several competing models to provide the best description of reality, based on the economic theory, it is nearly impossible for them to exactly reflect the ever-increasing complexity of the actual economy. For instance, structural changes in the financial system generated by deregulation and financial innovation can potentially make the economy more stable or less stable, so that outcomes can be good or bad. However, the models that policymakers rely on cannot capture these ongoing structural changes which can, in the short-run, pose difficult challenges for the actual conduct of monetary policy (Sellon, 2003).

With regard to the usefulness of macro-econometric models, some economists argue that it is inherently difficult to describe the complex economy with a series of equations. In addition, a far more important problem is that econometric analysis, based on the assumption that the past structure of the economy remains unchanged, leads to a high

possibility of policy ineffectiveness¹. In the small-open economies undergoing frequent institutional reforms as well as financial innovation, uncertainty tends to be further magnified, especially during periods when structural and technological changes are continually occurring. This is because small open-economies are subject to factors beyond domestic control such as changes in exchange rates and world prices of raw materials, and structural changes often create instability in economic activities (*e.g.*, money demand) which make economic movements difficult for policymakers to interpret as well as to explain with accuracy to the general public (Pill, 1999; Kim and Han, 2001; Kohn, 2007; and BOK, 2008b). After the currency crisis of 1997–1998, in particular, the Korean economy, a typical small-open economy, had experienced frequent and drastic changes in the institutional framework such as financial market liberalisation and monetary policy regime, along with the restructuring of large firms (Daewoo Group, Hanbo Group, *etc*) and investment trust companies.² These structural changes had undermined confidence in understanding of the structure of the economy, increased the risk of measurement error with respect to key variables, and as a result caused to increase the difficulty in forecasting them.

1.3 Research Questions and Objectives

In Korea, an inflation targeting (IT) regime was adopted in the aftermath of the 1997–1998 Korean currency crisis. The Bank of Korea (BOK) started valuing interest rates as

¹ Lucas (1976) argued that, whatever the correct model was before policy action, that action would itself change the structure of the economy, raising uncertainty about the transmission mechanism (Lucas's critique).

² The full opening of Korean financial markets was almost completed in 1998, shortly after the Korean currency crisis due to US' ongoing pressures for the Korean financial market liberalisation,

the instrument of monetary policy instead of monetary aggregates such as M2 and M3.

In recent years, central bank policymakers have faced more uncertainties than ever before when setting their policy interest rates. In this monetary policy environment, it is worth exploring whether the BOK has kept a conservative posture in moving the target of the Korean call rate, the equivalent of the US Federal Funds rate since the implementation of interest rate-oriented monetary policy. However, there is a lack of existing research on the operation of policy rates under uncertainty in Korea.

Together with this, the global financial crisis (GFC) of 2007–2009 provoked by the US sub-prime mortgage market recalls the following question: should central banks directly react earlier to control a sharp rise in asset prices? Historical episodes witness that boom-bust cycles in asset prices, especially house prices, can be damaging to the real economy. In Korea, house prices have evolved under uncertainties, and in the process house-price bubbles have been formed over a long period of time. Therefore, in recent years, central bankers and academia in Korea have paid great attention to fluctuations in asset prices.

In this context, the thesis will focus on exploring the following issues in detail:

- What are the different types of uncertainty faced by central banks, and how can these be formally introduced into macroeconometric models for monetary policy analysis?
 - Is the behaviour of monetary policymakers in practice consistent with the predictions made by the theoretical models of monetary policy under uncertainty?
 - How has such uncertainty affected the actual operation of monetary policy in Korea?
- and

- Should central banks directly react earlier to control the sharp increase in asset prices, *i.e.*, prick the bubble?

Based on these research questions, this thesis aims: *i)* to set up theoretical and empirical models of monetary policy under uncertainty; *ii)* to examine the effect of uncertainty on the operation of monetary policy since the adoption of interest rate-oriented policy; and *iii)* to investigate whether gradual adjustment in policy interest rates can be explained by uncertainty in Korea. Another important aim is *iv)* to examine whether house-price fluctuations should be taken into account in formulating monetary policy in Korea.

1.4 Research Contributions

The contributions of this thesis are fourfold:

- to discuss monetary policy shocks and uncertainties in the actual conduct of monetary policy, and to investigate the characteristics of policy rate movements, *i.e.*, stylised facts and the degree of interest-rate smoothing from the Korean perspective.
- to understand the BOK monetary policy management by incorporating parameter uncertainty into the model, using Korean data, and to provide the implications of parameter uncertainty for monetary policy decision-making.
- to examine the magnitude of measurement errors in the output gap and inflation in Korea, and to estimate the optimal policy rule and calculate the loss values under data uncertainty, and
- to add to the debate on asset prices and monetary policy by formulating the structural

models based on the New Keynesian approach, and to examine which policy choice could be more effective in terms of validity between the one pursuing price stability only and the other one considering asset-price volatility as well as price stability in Korea.

Overall, this thesis will contribute to the scarce empirical literature on analyses using dynamic programming techniques with the VAR approach in the presence of uncertainty, and theoretical and empirical formulation and discussion regarding asset prices and monetary policy based on the New Keynesian approach.

1.5 The Structure of the Thesis

The remainder of this thesis is structured as follows: first of all, Chapter 2 provides in-depth surveys of the theoretical and empirical literature on monetary policy under uncertainty. This chapter begins with defining uncertainty, and investigates two views (*conservatism vs. activism*) regarding monetary policy in the face of uncertainty. Various types of uncertainty explained and analysed in the existing literature will be discussed and implications of each type of uncertainty will be reviewed. And in turn, this chapter will conduct a literature survey on the relationships between asset prices and monetary policy, along with the relationships between asset prices and financial stability.

Chapter 3 discusses the objectives of monetary policy, reviews the development of the monetary policy framework in Korea, which has evolved from a monetary targeting to a (full-fledged) inflation targeting (IT) regime. In turn, we attempt to identify monetary policy shocks and uncertainties in the actual conduct of monetary policy, and investigate the characteristics of policy rate movements in Korea. We also show a

theoretical derivation of the policy reaction function with a partial adjustment term, examine the degree of interest-rate smoothing in Korea through empirical analyses using OLS and GMM estimations, and discuss why central banks smooth interest-rates.

Chapter 4 provides the methodology used for analysis of optimal monetary policy rules under parameter uncertainty. The models used in this chapter are almost identical to those used by Sack (2000). The aim of this chapter is to investigate whether gradual movements in policy rates can be explained by parameter uncertainty even in the absence of an interest-rate smoothing motive, and to examine the effect of parameter uncertainty on monetary policy in Korea. We found that the call money rate has been shown to be similar to the optimal policy rate path under parameter uncertainty since the introduction of an interest rate-oriented monetary policy in Korea. This finding confirms that monetary policy in Korea has been conducted in a similar way to the optimal policy derived under the assumption that such uncertainty exists. And, gradual movements in policy rates do not necessarily indicate that the central bank has an interest-rate smoothing incentive. Uncertainty and the dynamic structure of the economy can account for a considerable portion of the observed gradual movements of the interest rate.

Chapter 5 focuses on how the presence of data uncertainty influences policy-making, examining how the optimal policy rules change when uncertainty on data increases. The main finding is that the greater the output-gap uncertainty, the smaller the output-gap response coefficients in the optimal rules; and in a similar vein, the greater the inflation uncertainty, the smaller the inflation response coefficients. The optimal policy rules derived by using data without errors showed the large size of the output-gap and inflation

response coefficients. Central banks face a large amount of uncertainty about the actual state of the economy when choosing their policy rates. The evaluation of monetary policy in most empirical studies relies on the unrealistic assumption that policymakers know for sure the current state of the economy with no errors. Data uncertainty may be one of the sources explaining why monetary policymakers act less aggressively in setting their interest rate instrument at each period of time.

Chapter 6 explores how central banks should conduct monetary policy in the presence of high volatility in house prices and asset-price bubbles. In this chapter, we build a forward-looking structural model that consists of the Phillips curve, the IS curve and monetary policy reaction rules, forming a small dynamic stochastic general equilibrium (DSGE) model. In particular, this chapter will provide the discussions on the theoretical framework of a hybrid version of the New Keynesian (NK) model, followed by the state-space representation of the baseline model and the model solution method. In addition, we discuss the optimal control problem focusing mainly on the central bank's objective function which will be used to compare the central bank's responses. By using the hybrid version of the NK model, we will examine what should be the best response of central banks to changes in asset prices such as house prices in order to achieve economic stability in Korea. Through model simulations and impulse response analyses, we will show whether the central bank can reduce its loss values in terms of economic volatility, thereby leading to growing economic stability, when it responds more directly to fluctuations in house prices.

Chapter 7 summarises and concludes the thesis, and finally discusses some directions for future research.

Chapter 2

Literature Review of Uncertainty, Asset Prices and Monetary Policy

2.1 Introduction

Central banks face a variety of uncertainties when implementing monetary policy. The causes of such uncertainties are diverse. They may include our lack of understanding about the monetary policy transmission mechanism, uncertain reactions of markets to monetary policy decisions, economic agents' expectations on current and future economic policies or conditions, and imperfect forecasting of future events. Since these factors may give rise to changes in the economic outlook and unintended policy outcomes, central banks need to develop and implement policies in consideration of multiple possible consequences that may arise from diverse uncertainties.

Knight (1921) defined uncertainty as a situation where one cannot know the probability distribution of an event, thereby distinguishing uncertainty from risk (to

which a specific probability distribution can be applied). However, in practice, risk and uncertainty are often treated in a similar way. For instance, an escalation in risk in the financial and foreign exchange markets is often regarded as an increase in current or future uncertainty. In general, since the probability distribution of risks is recognised as being subjective and differing across individuals, financial and portfolio theory³ do not draw a clear distinction between uncertainty and risk.

Over the past half century, much effort has been devoted to explaining economic phenomena and understanding the transmission mechanism of monetary policy by using statistical models that describe relationships between a relatively small set of macroeconomic variables. Such models can provide a useful description of the economy. However, no model can capture the complexities of the actual economy.

The Brainard conservatism principle implies that central banks facing a variety of uncertainties should adjust their policy interest rates⁴ in a conservative manner. Since its introduction, the principle has become one of the important principles for central banks to follow in conducting monetary policies⁵. In accordance with the principle (and in order to avoid reversals in the direction of monetary policy), central banks tend to adjust interest rates gradually. Recently, however, some academic economists and policymakers at central banks argue that conservatism under

³ See, for example, Dow and Werlang (1992) and Epstein (2010).

⁴ In this thesis, the term, the ‘policy interest rate’, is often referred to interchangeably as the ‘key (interest) rate’ meaning the main policy instrument that central banks use to signal their monetary policy stances.

⁵ There is an extreme conservatism in monetary policy rules, for example, the ‘Friedman rule’ which makes uncertainty irrelevant but advocates setting the nominal interest rate at zero. According to the Friedman rule, the opportunity cost of holding money faced by private agents should equal the social cost of creating additional fiat money. It is assumed that the marginal cost of creating additional money is zero. Hence, nominal interest rates should be zero (see Friedman (1959)).

uncertainty is not always desirable; and in some cases, activism can be more effective in reducing inflation and volatility of the real economy.

This debate is pertinent to the issue of how policymakers ought to respond to fluctuations in asset prices. It is argued that central banks need to respond to changes in asset prices only when their stability is under threat; for instance, when inflationary pressures are likely to rise due to a pick-up in asset prices (Smet, 1997; Bernanke and Gertler, 1999). In other words, central banks should not respond to asset prices *per se*, but rather to changes in the outlook for inflation and aggregate demand arising from asset-price fluctuations. This view even insists that central banks should not use monetary policy to prick an asset-price bubble. This somewhat cautious response is in contrast to arguments for strong pre-emptive responses to potentially destabilising movements in asset prices. The reasoning behind this argument is that interrelations between asset prices and interest rates are uncertain, and moreover that central banks always face uncertainty whenever they attempt to measure asset price levels and assess the possible existence of a bubble in the asset markets.

Others, on the contrary, contend that central banks should take measures upon any sudden changes in asset values actively and pre-emptively for the sake of financial stability, regardless of the stability of asset prices and general prices. Recently, emphasis has been placed on this view due to the global financial crisis (GFC) of 2007–2009 triggered by the US sub-prime mortgage market.

In this chapter, a survey on previous studies will be conducted, being classified into two categories: monetary policy under uncertainty, and asset prices and monetary policy. First of all, Section 2.2 reviews a number of existing studies with respect to monetary

policy under uncertainty. The section introduces two opposing views on measures central banks should take in the presence of uncertainty, and explains the implications of data and parameter uncertainties in relation to monetary policy through simple theoretical models. Next, Section 2.3 deals with the previous literature on the relationships between asset prices and monetary policy, along with the relationships between asset prices and financial stability. The section examines, in particular, the linkages between asset prices and financial stability after the GFC and their implications on monetary policy. Section 2.4 summarises and concludes.

2.2 Monetary Policy under Uncertainty

2.2.1 Uncertainty and Risk: Definition

In general, *uncertainty* refers to a situation where the likelihood of future events is not measurable. Knight (1921) was one of the first economists to distinguish between *uncertainty* and *risk*. This distinction was made as part of an explanation of the role of entrepreneur and profit in the production process.⁶ According to him, while *risk* refers to the randomness with experimentally known or knowable probabilities, *uncertainty* refers to the randomness with unknowable probabilities. LeRoy and Singell (1987) elaborate on Knight's distinction between uncertainty and risk by defining *Knightian* uncertainty as a situation with no objective or publicly verifiable probability distribution, in contrast to *risk*. This type of 'Knightian uncertainty' with

⁶ Knight (1921)'s view is that profits accruing to entrepreneurs are justified and explained by the fact that they bear the consequences of the risks (uncertainties) inherent in the production process that cannot be readily quantified. See, for a more detailed explanation, Cagliarini and Heath (2000).

unknown probabilities is often called '*pure*' uncertainty. To sum up, when policymakers can estimate the probability distribution of a certain event, this event is called *risk*. In contrast, if policymakers cannot calculate the probability distribution, this event is called *uncertainty*.

In spite of these strict distinctions, monetary policymakers frequently use the broader concept of 'uncertainty' which encompasses both 'Knightian uncertainty' and 'risk'. For example, Greenspan (2003) argues that:

Uncertainty is not just an important feature of the monetary policy landscape; it is the defining characteristic of that landscape. As a consequence, the conduct of monetary policy in the United States at its core involves crucial elements of risk management, a process that requires an understanding of the many sources of risk and uncertainty that policymakers face and the quantifying of those risks when possible. It also entails devising, in light of those risks, a strategy for policy directed at maximizing the probabilities of achieving over time our goal of price stability and sustainable economic growth that we associate with it.

And, Kohn (2006) also states that:

I use the words 'risk' and 'uncertainty' loosely. Although economists usually apply the former term to random events with known likelihood and the latter to possibilities whose numerical probability is unknown, we often do not know for sure in practice about actual probability distributions to make a sharp distinction between the two concepts.

2.2.2 Two Views on Monetary Policy under Uncertainty

There are many theoretical and empirical papers which study how central banks should conduct monetary policy in a world of pervasive uncertainty. The debate on this issue has existed in the economic literature for at least half a century. But these papers do not always lead to the same conclusions. The two different main views on monetary policy in the presence of uncertainty will be explored as follows.

2.2.2.1 Conservatism

It is widely believed that policymakers facing uncertainty about the effects of policy changes on the economy should react more prudently than when there is no uncertainty. Many empirical analyses of central banks' interest rate policy illustrated that their actual interest rate policy shows a timid pattern of movements, compared to that derived under the absence of uncertainty. For instance, Debelle and Cagliarini (2000) showed that the US Federal Reserve generally moved its interest rate multiple times in the same direction before reversing its policy stance: over the period from January 1992 to August 2000, policy changes in the same direction as the previous change are more common than policy reversals. The average duration between policy adjustments tends to be much longer in the case of policy reversals. Moreover, the average size of the steps at turning-points, 25 basis points (hereafter referred to as 'bp'), is found to be smaller than that of continuations, 35 bp (*i.e.*, a consecutive increase or decrease). As reported in Table 2.1, this tendency can be observed in developed countries such as the UK, Japan, Canada and Australia.

Table 2.1: Policy Rate Adjustments in Selected Countries: January 1992–August 2000*

	Number of changes		Average duration (in days)			Average size of change (in basis points)		
	Continuations (++ or --)	Reversals (+- or -+)	All	Continuations (++ or --)	Reversals (+- or -+)	All	Continuations (++ or --)	Reversals (+- or -+)
US	18	5	133	67	374	33	35	25
UK	27	5	96	81	179	41	43	30
Germany/ Euro area	84	10	33	22	123	11	10	20
Japan	8	1	350	326	546	50	63	23
Sweden	50	5	48	33	195	27	27	28
Canada	36	5	52	42	123	34	35	25
Australia	16	3	168	117	438	57	58	50

Note: * Except Sweden (since December 1992) and Canada (since July 1994)

Source: Debelle and Cagliarini (2000).

The attenuated adjustment of the policy instrument was first analysed by Brainard (1967), who used a static macroeconomic model with a known probability distribution of uncertain parameters. In Brainard’s analysis, a specific type of the model framework called “linear-quadratic” was used, and uncertainty about one of the parameters that specify the model was introduced. He argued that when policymakers are unsure as to the true parameters of the model, they should adjust policy instruments in the same direction which the certainty equivalence principle⁷ prescribes, but by less. This seminal prescription is named the ‘*Brainard conservatism principle*’ (BCP) by Blinder (1997, p.11; 1998)⁸, and it is often referred to as “gradual” monetary policy. Over the last few decades, this gradualism has come to be regarded as identical to *caution* (Barlevy, 2009), and Brainard’s intuition has often been cited as providing a rationale to justify a cautious and gradualist approach to monetary policy-making in the face of uncertainty.

⁷ This concept will be discussed in Subsection 2.2.3 in further detail.

⁸ Reinhart (2003) used the term “attenuation”, which is a more neutral term, instead of “conservatism.”

2.2.2.2 Activism

In recent years, there have been a number of studies advancing counter arguments to the Brainard conservatism principle (BCP). These studies argue that even in the presence of uncertainty, the gradual adjustment of policy rates is not always desirable, and a more aggressive policy can be more appropriate according to what the nature of uncertainty is.

In an environment where there are growing expectations of interest rate adjustments, if central banks move their key policy rate in small steps, market participants who recognise the pattern of interest-rate changes, react less to a change in policy than would otherwise be the case, anticipating that there will be further adjustments of policy rates in the same direction. Accordingly, their delayed reactions cause the ineffectiveness of policy change. This insufficient policy effect leads central banks to adjust policy interest rates inevitably again⁹.

In the late 1990s and early 2000s, central bankers of the major countries such as the United Kingdom and the United States argued that interest rate policy should be conducted in a more aggressive way. The Bank of England's policymakers remark that:

“ ... so long as any (rapid) policy reversals (*e.g.*, cutting rates very shortly after having raised them) could be properly explained by new developments or improved analysis of the (economic) outlook, they need not create confusion about policy goals ... there were no benefits in delaying changes in rates to

⁹ Caplin and Leahy (1996) argued that very gradual reductions in interest rates may prove ineffective in boosting economic activity. The reason is that small reductions in interest rates are less likely to promote a response, and hence more likely to be followed by further cuts. A vicious circle develops in which cautious policy is unsuccessful not only because it is cautious, but also because investors anticipate the greater possibility of failure and delay investment. In contrast, aggressive policy initiatives, because they are more likely to be successful and hence temporary, create a climate of urgency that promotes a more immediate response.

reduce the risk of reversals, and it was better to make changes as soon as they appeared necessary. Also, the desire to minimise the risk of policy reversals was likely to mean that interest rate changes would, on average, be made too late ...”.

(Minutes of Monetary Policy Committee meeting, Bank of England, 1998).

In addition, Greenspan (2001) in his congressional testimony remarks that:

“... because the advanced supply-chain management and flexible manufacturing technologies may have quickened the pace of adjustment in production and incomes and correspondingly increased the stress on confidence, the Federal Reserve has seen the need to respond more aggressively than had been our wont in earlier decades. Economic policy-making could not, and should not, remain unaltered in the face of major changes in the speed of economic processes ...”.

Early studies demonstrating that cautious policy action is not always an appropriate response include Chow (1975) and Craine (1979). Both show that uncertainty can lead to a more active policy than in the certainty equivalence¹⁰ case — or what we might dub *activism* of policy.

Since Chow’s and Craine’s pioneering analysis, many other economists have engaged in research on monetary policy under uncertainty, and have emphasised circumstances in which parameter uncertainty should lead policymakers to vary the policy instruments more than would be optimal in the absence of such uncertainty. So, it has been argued that “widely held views” that policy should be more passive may be

¹⁰ A more detailed discussion on this concept will be presented in Subsection 2.2.3.

wrong. For example, uncertainty about the persistence of the inflation process can lead policymakers to adjust interest rates more vigorously so as to reduce uncertainty about the future developments of inflation (Shuetrim and Thompson, 1999; Söderström, 2000, 2002; Levin and Williams, 2003; and Kimura and Kurozumi, 2007).

Notably, since the introduction of the robust control approach to monetary policy-making, which is aimed at minimising the losses associated with the worst possible outcomes, it is, all in all, stressed that a stronger reaction to uncertainty, particularly about the model, is a more appropriate policy (Stock, 1999; Giannoni, 2002, 2007; Onatski and Stock, 2002; Tetlow and von zur Muehlen, 2001; and Hansen and Sargent, 2008).

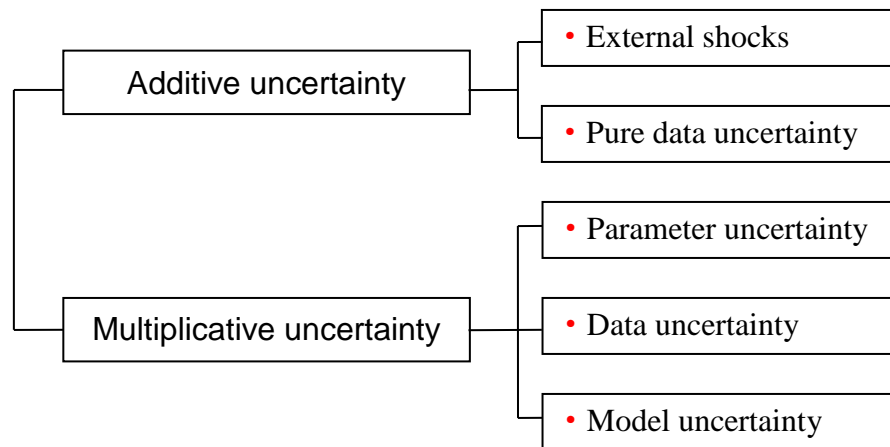
2.2.3 The Types of Uncertainty and their Policy Implications

Various types of uncertainty are explained and analysed in the theoretical and empirical literature. Poole (1998) provides one possible classification of uncertainty that divides uncertainty into five categories: the data; future events, shocks and disturbances; how the economy works; market reactions to the Fed's monetary policy; and market anticipations of the Fed's policy. Srour (1999) puts more emphasis on uncertainty about coefficients, time lags and the nature of shocks. From the policymakers' perspective, Freedman (1999) discusses four types of uncertainty: additive uncertainty; multiplicative uncertainty; model uncertainty; and uncertainty about data and the output gap. Similarly, Dennis (2005) notes that each type of uncertainty could lead to different implications for how central banks should conduct monetary policy, and presents one possible classification of the uncertainty faced by monetary policymakers into three categories: data uncertainty; parameter uncertainty; and model uncertainty. Bernanke (2007) also highlights three areas of

economic uncertainty: the current state of the economy; the structure of the economy (including the transmission mechanism of monetary policy); and the way in which private agents form expectations about future economic developments and policy actions.

In this section, based on various classifications, uncertainties associated with policy responses and effects will be categorised and implications of each type of uncertainty will be reviewed in more detail.

Figure 2.1: General Classification of Uncertainty



2.2.3.1 Additive Uncertainty

The external shocks and the future time paths for the exogenous variables driving the macroeconomy are, in all likelihood, uncertain. The possibility of unexpected events caused by a demand or supply shock, or both, can be expressed by adding disturbance terms to the model. These stochastic terms, which enter the models additively, are called *additive uncertainty*, capturing shocks in the models. On the theoretical side, additive uncertainty about shocks is said to be the simplest form of uncertainty. Together with

additive shocks, another source of additive uncertainty arises from incomplete data itself when there are no other types of uncertainty. This kind of uncertainty is referred to as *pure data uncertainty*.

A general principle in dealing with this type of uncertainty is to follow the well-known ‘*certainty equivalence principle*’ (CEP)¹¹: a policy rule that is optimised under the assumption of the absence of uncertainty is still optimal in the presence of such uncertainty (see, for example, Selody (2001) and Noyer (2008)).

The classical research papers on optimal policy rules consider only additive sources of uncertainty. In a standard linear-quadratic framework with additive uncertainty, the CEP implies that the optimal policy rule is the same as if there were no uncertainty.¹² Since its introduction by Simon (1956) and Theil (1958), this principle has played an important role in policy discussions.¹³

According to this principle, in an economy where a transition equation (*i.e.*, a Phillips curve or an aggregate supply equation) is linear and the central bank’s objective function has a quadratic form, additive uncertainty has no impact on the policy-making process. Thus policy decisions made by central banks that take into account this type of uncertainty are the same as those of the central banks that ignore such uncertainty. In this case, the optimal policy choice of central bankers who optimise their objective function is just to react to the disturbances under the premise that the certainty equivalence holds.

¹¹ An early expression of this argument may be found in Tinbergen (1952). See Clarida *et al.* (1999) for the discussion of procedure.

¹² In other words, the certainty equivalence would hold if the central bank’s objective function (or a loss function) was quadratic and the transition equation (*i.e.*, the Phillips curve) was linear.

¹³ See Swanson (2004), Svensson and Woodford (2003), and Woodford (2003a) for more recent treatments.

This is the reason why the concept of additive uncertainty has not been regarded as an important element in the modelling of optimal policy, and uncertainty, for a long time, has received little attention from academics and central bankers.

A Simple Model of Additive Uncertainty

(The Deterministic Case)

Before introducing uncertainty into the model, consider a simple model that assumes a *certain* world with only one target and one instrument¹⁴. For simplicity, suppose a target variable, π depends linearly on an instrument variable, P , that is:

$$\pi = \alpha P + v, \quad (2.1)$$

where π and P stand for a target variable (say, inflation rate) and policy instruments (*e.g.*, the short-term nominal interest rate) of monetary policy, respectively. The coefficient, α (< 0) measures the degree to which policy influences the target variable (a policy multiplier), and it is assumed to be known to the policymakers. In addition, π can be affected by other variables, as summarised by the last term, v . This term could include exogenous variables such as a demand or/and a supply shock, which have a direct impact on π , and it is also assumed to be known to policymakers.

This relationship between π and P implies that a rise in a policy instrument leads to a decrease in inflation. In this model, assuming a world of *certain*ty, the optimal policy, P^* for the attainment of a target level, π^T can be computed as:

¹⁴ The term ‘instrument’ refers to a variable that the monetary policymaker can control so that the target variable will equal to some prespecified level.

$$P^* = \frac{\pi^T - v}{\alpha}. \quad (2.2)$$

In the deterministic case, by setting its policy instrument as Equation (2.2), a monetary policymaker can achieve a target level of inflation, π^T exactly.

(The Case with Additive Uncertainty)

To incorporate additive uncertainty into the policymaker's problem, consider the simple *linear* model with again only one target and one instrument, given by:

$$\pi = \alpha P + u, \quad (2.3)$$

where all the notations (π , P and α) except the *additive* stochastic term u are the same as in the deterministic case. As in Equation (2.1), the term u represents exogenous variables (*i.e.*, unforeseen external shocks) which have a direct impact on π . In this case, *additive* shocks cause a variable (say, π) to deviate from the path derived by its identified determinants. This formulation, however, now assumes that u is a white noise disturbance with mean \bar{u} and variance σ_u^2 . In other words, the policymaker knows the mean \bar{u} and the variance σ_u^2 , while not knowing the value of the shock itself. The additive term is meant to capture uncertainty the policymaker faces with regard to attainment of the targeted level of inflation π^T .

If the policymaker's goal is to minimise the expected squared deviations between actual inflation, π_t and its target, π^T , the loss function is written as:

$$L^{au} = E[(\pi - \pi^T)^2]. \quad (2.4)$$

Equation (2.4) has the standard quadratic form of the loss function. It implies that the goal of the policymaker is to find the value of policy instrument, P^* which enables him to obtain the least value of the loss function. The loss function can be rewritten as:

$$\begin{aligned} L^{uu} &= E[(\pi - \bar{\pi} + \bar{\pi} - \pi^T)^2] \\ &= [\sigma_{\pi}^2 + (\bar{\pi} - \pi^T)^2], \end{aligned} \quad (2.5)$$

where $\bar{\pi} = E(\pi)$ and $\sigma_{\pi}^2 = \text{Var}(\pi) = E(\pi - \bar{\pi})^2$.¹⁵ Equation (2.5) shows that the loss function can be decomposed into the conditional variance of the variable given all information available at time t and the expected squared deviations of the variable from its target. Since $\bar{\pi} = \alpha P + \bar{u}$ and $\sigma_{\pi}^2 = \sigma_u^2$, we can rewrite Equation (2.5) as:

$$L^{uu} = \sigma_u^2 + (\alpha P + \bar{u} - \pi^T)^2. \quad (2.6)$$

To obtain the optimal value, P^* , we take the partial derivative of Equation (2.6) with respect to P and set this equal to zero. After rearranging, the following result yields:

$$P^* = \frac{\pi^T - \bar{u}}{\alpha}. \quad (2.7)$$

As seen in Equations (2.2) and (2.7), if $u = \bar{u} = v$, the optimal policy setting under additive uncertainty is equal to that under certainty, what has been referred to as ‘*certainty equivalence*.’ This means that to formulate the optimal policy, the policymaker could regard u term as being equal to its expectation and proceed as in the certainty case.

¹⁵ In the second expression of Equation (2.5), the cross product terms from the multiplication drop out because $E[\pi - \bar{\pi}] = 0$.

In sum, in the simple model with additive shocks like Equation (2.3), the only uncertainty is whether the economy will deviate from the path that policymakers expect because of what are called ‘additive shocks’. In this case, the best choice that policymakers could make might be to ignore the impact of uncertainty on the economy.

2.2.3.2 Multiplicative Uncertainty

It was not until the late 1960s that other types of uncertainty along with additive shocks started to be taken into account explicitly in monetary policy models. Central bank policymakers and academic economists started to give attention to the multiplicative form of uncertainty. Brainard (1967) argues that the multiplicative types of uncertainty (*e.g.*, uncertainty about parameters), can provide justification for the practice of an adjustment of policy instrument.

Multiplicative uncertainty can take diverse forms. From an analytical viewpoint, it can be classified into three broad categories: *parameter uncertainty*, *data uncertainty* and *model uncertainty* (see, for example, Poole (1998), Dennis (2005), Bernanke (2007) among many others). In practice, existing studies into the effects of uncertainty, and the design of optimal policy in the presence of uncertainty, have focused on these three types of uncertainty. Conclusions on policy implications are contingent on the forms of multiplicative uncertainty and the methodology for analysis.

A. Parameter Uncertainty

Parameter uncertainty refers to uncertainty regarding the numerical values of

parameters or coefficients in a given macroeconometric model of the economy.¹⁶ More specifically, it is related to uncertainty about the monetary transmission mechanism, or uncertainty concerning the exact effect of the central banks' principle instrument (*i.e.*, the short-term nominal interest rate) on economic activities. This uncertainty is, therefore, often called *multiplier* uncertainty. So parameter uncertainty gives rise to multiplicative uncertainty.

In the case of parameter uncertainty, a key result is that of Brainard (1967)'s seminal work. Brainard points out its implications for central banks: monetary policymakers should react in a less aggressive fashion to shocks to variables associated with uncertain parameters in the monetary policy transmission process. This point of view implies that if policymakers face uncertainty about key parameters in the model, for example, the response of output to interest rates and the response of inflation to the output gap, they should typically moderate changes in their policy interest rates in response to a given change in the output gap or to a given change in the deviations of actual inflation from its target level. Like this, Brainard's argument relies exclusively on a specific type of uncertainty, *i.e.*, uncertainty facing policymakers regarding the effects of their actions on the economy.

The Brainard Model

In order to consider the parameter uncertainty case in which the policymaker views the parameter as a random variable, let us replace Equation (2.3) with:

¹⁶ Some researchers (for example, Debelle and Cagliarini (2000), Onatski and Stock (2002), among others) regard parameter uncertainty as a particular form of model uncertainty, where only uncertainty about the variables included in the particular model is taken into account.

$$\pi = \tilde{\alpha}P + u, \quad (2.8)$$

where the notation except the coefficient, $\tilde{\alpha}$, is the same as in Equation (2.3). The coefficient ($\tilde{\alpha}$) attached to the policy variable is assumed to be a random variable with mean, $\bar{\alpha}$, variance, $\sigma_{\tilde{\alpha}}^2$ and covariance, $Cov(\tilde{\alpha}, u) = \sigma_{\tilde{\alpha}u}$ (i.e., $\rho\sigma_{\tilde{\alpha}}\sigma_u$). That is, it is assumed that policymakers know $\bar{\alpha}$, $\sigma_{\tilde{\alpha}}^2$ and $Cov(\tilde{\alpha}, u)$: they do not know the exact value of $\tilde{\alpha}$, but know its distribution in advance. And, as before, the mean and the variance of the additive term, u are \bar{u} and σ_u^2 , which are known to the policymakers as well.

This formulation assumes that policymakers are uncertain about the effect of a policy change, as measured by $\tilde{\alpha}$ that multiplies the choice of P , as well as about the factors that directly affect π , as captured by the additive stochastic term u . In this model, the policymakers face two sources of uncertainty: parameter and additive uncertainties. With these assumptions, the variance of inflation can be computed as:

$$\sigma_{\pi}^2 = \sigma_{\tilde{\alpha}}^2 P^2 + \sigma_u^2 + 2\rho\sigma_{\tilde{\alpha}}\sigma_u P, \quad (2.9)$$

where ρ is the correlation coefficient between $\tilde{\alpha}$ and u . Here, the variance of target variable (inflation) is influenced by the variance of the multiplier coefficient $\tilde{\alpha}$, the setting of the policy instrument P and the correlation coefficient ρ , as well as by the variance of the additive term σ_u^2 .

As mentioned earlier, the policymakers will choose P so as to minimise the expected loss, that is:

$$L^{pu} = [\sigma_\pi^2 + (\bar{\pi} - \pi^T)^2], \quad (2.10)$$

where $E(\pi) = \bar{\pi} = \bar{\alpha}P + \bar{u}$. Again, the loss function can be decomposed into the conditional variance of the variable given information at time t and the expected squared deviations of the variable from its target. Using Equation (2.9) to substitute for σ_π^2 , we can rewrite Equation (2.10) as:

$$L^{pu} = [\sigma_{\bar{\alpha}}^2 P^2 + \sigma_u^2 + 2\rho\sigma_{\bar{\alpha}}\sigma_u P + (\bar{\alpha}P + \bar{u} - \pi^T)^2], \quad (2.11)$$

thus, the optimal policy would give:

$$P^{**} = \frac{\bar{\alpha}(\pi^T - \bar{u}) - \rho\sigma_{\bar{\alpha}}\sigma_u}{\bar{\alpha}^2 + \sigma_{\bar{\alpha}}^2}. \quad (2.12)$$

From Equation (2.12), it is easily seen that the certainty equivalence principle does not hold¹⁷. In the simple case when $\rho = 0$, Equation (2.12) becomes:

$$P^{**} = \frac{\bar{\alpha}(\pi^T - \bar{u})}{\bar{\alpha}^2 + \sigma_{\bar{\alpha}}^2}. \quad (2.13)$$

In general, under the conditions where there is parameter uncertainty (that is, $\sigma_{\bar{\alpha}}^2 > 0$), the following relationship is obtained:

$$P^{**} = \frac{\bar{\alpha}(\pi^T - \bar{u})}{\bar{\alpha}^2 + \sigma_{\bar{\alpha}}^2} < \frac{\pi^T - \bar{u}}{\alpha} = P^*. \quad (2.14)$$

¹⁷ Notice here that as $\sigma_{\bar{\alpha}}^2$ (and hence $\sigma_{\bar{\alpha}}\sigma_u$ and ρ) $\rightarrow 0$ and $\bar{\alpha} = \alpha$, then Equation (2.12) reduces to Equation (2.7). This is the case of no multiplier uncertainty, that is, certainty equivalence holds.

This result implies that the certainty equivalence principle no longer holds under parameter uncertainty. In other words, the optimal policy under uncertainty about the effect of a policy change will lead the policymakers to adjust their policy instrument less aggressively relative to the case where they know the effect of a policy change on the target variable with certainty.

Ever since the theoretical analysis by Brainard (1967), uncertainties about the impact policy actions have on the economy have been studied by many other researchers. But, in fact, the results regarding the strength of the optimal monetary policy response can go either way: *conservatism* or *activism*. However, because uncertainty about the parameter we consider is inherently multiplicative not additive, certainty equivalence does not hold regardless of whether individual results support conservatism or activism.

Parameter Uncertainty and Conservatism

There have been a number of *theoretical* research results supporting Brainard's classic analysis. Among them, Svensson (1999a), analysing a special case where only inflation enters the central bank's loss function, shows that uncertainty about the policy multiplier can lead to a more muted policy path in response to current inflation and output. Estrella and Mishkin (1999) also provide an illustrative theoretical analysis that demonstrates the "less activist" nature of optimal policy in the face of uncertain parameters. Specifically, they show that uncertainty about the parameter, which measures the impact of interest rate on output (*i.e.*, the degree of the interest-rate sensitivity of aggregate demand), will cause the policymakers to be less aggressive in their policy reaction. And, Clarida *et al.* (1999), with a forward-looking theoretical model, illustrate how model parameter uncertainty

could introduce caution in policy response, and argue that this effect can provide one rationale for a smoother path of interest rate than the certainty equivalence principle.

There is also much *empirical* research which supports Brainard's theoretical results. First of all, Debelle and Cagliarini (2000) find that for the Australian economy, the mean parameter uncertainty about the interest rate sensitivity of output leads to a less aggressive optimum policy in the model. Sack (2000) compares the optimal interest rate path derived from an unrestricted vector autoregressive (VAR) model of the US economy under multiplicative uncertainty with the optimal interest rate path in which multiplicative uncertainty is presumed not to be present. He concludes that the presence of uncertainty can account for a considerable portion of the gradualistic behaviour of the US Federal Funds rate. For the UK economy, Martin and Salmon (1999) also reach the same conclusion using Sack's method (an unrestricted VAR). Results supporting conservative policy have been obtained by Hall *et al.* (1999). Using a five-equation empirical model of the UK economy, they find that policymakers should respond by taking a cautious stance to shocks in the face of parameter uncertainty. What these studies have in common is that they are based on backward-looking models.

Parameter Uncertainty and Activism

In contrast to the Brainard conservatism principle, there are many counter arguments suggesting that a more aggressive response to shocks may be more appropriate when the central bank encounters parameter uncertainty, particularly regarding the degree of inflation persistence. Söderström (2002), using theoretical models, investigates the effects of multiplicative parameter uncertainty in a dynamic backward-looking model with the Phillips curve, and demonstrated that uncertainty about the degree of inflation persistence

induces the central bank to take a more active policy stance than would be the case in the absence of uncertainty. Similar results are found by Kimura and Kurozumi (2007). By using Bayesian methods¹⁸, they illustrate how uncertainty on some structural deep parameters, capturing the underlying dynamic decision-making behavior of consumers and firms in the model results in a more aggressive policy reaction to shocks, overturning Brainard's classic findings. They argue that increases in uncertainty about inflation dynamics leads the central bank to place a higher weight on price stability than in the absence of uncertainty. In consequence, central bank policymakers should react more aggressively in the face of uncertainty in the parameters driving inflation persistence. Their analysis is based on the micro-founded forward-looking dynamic model and the assumption of a non-linear loss function. Notably, they considered the effects of both loss-function uncertainty and the positive correlation between the policy multiplier and transmission of shocks, which have been ignored in most of the existing studies.

Besides uncertainty in the parameter capturing inflation persistence, there are many papers showing that Brainard's classic wisdom might be overturned in the other parameter uncertainties. First of all, Shuetrim and Thompson (1999) attempt to generalise Brainard's model to a multi-period horizon and multi-variate model, using Australian data to examine the effect of parameter uncertainty. The conclusion they obtain is that while uncertainty about the interest-rate sensitivity of output decreases the willingness of policymakers to

¹⁸ When economists typically model decision-making under uncertainty, it is assumed that policymakers can assign explicit probabilities to the various scenarios they might face. Given these *prior* probability distributions, they can compute each policy's *expected loss*, that is, the *expected* social cost of the outcomes implied by each policy. The presumption, here, is that the policy rules associated with the smallest expected loss may be optimal to policymakers. This method is called the Bayesian approach, which searches for the monetary policy rule whose largest loss is minimised (Barlevy, 2009; Giannoni, 2007). This approach was first started by Brainard (1967) and has been followed by numerous studies such as Clarida *et al.* (1999), Wieland (2003), Estrella and Mishkin (1999), Hall *et al.* (1999), Martin and Salmon (1999), Svensson (1999a), Sack (2000), Rudebusch (2001) and Söderström (2000, 2002).

change interest rates as in Estrella and Mishkin (1999), uncertainty about the dynamic structure of the model can lead to the opposite result: the policymakers facing uncertainty should adjust interest rates more aggressively than would be the case in the absence of uncertainty.

Giannoni (2002) considers uncertainty about the key parameters of the simple forward-looking structural model and proposed a general method based on a property of zero player games to obtain robust optimal policy rules when the true model is known and model uncertainty is regarded as uncertainty about parameters of the structural model. As a result, he found that robust optimal Taylor rules generally imply a *stronger* response of the interest rate to fluctuations in policy goals such as inflation and the output gap than is the case in the presence of certainty. Giannoni (2007) also characterises a robust optimal policy rule in a simple forward-looking model, when the policymaker encounters uncertainty about the parameters of the structural model and the nature of the shock processes. He found that the robust optimal policy rule involves a stronger response of the interest rate to fluctuations in inflation and the output gap than is the case in the absence of uncertainty.

Levin and Williams (2003) analyse the consequences of parameter uncertainty for policy when policy objectives depend on the model's structural parameters governing the transmission process of monetary policy. As in Kimura and Kurozumi (2007), their papers employed Bayesian methods, and showed how optimal monetary policy is affected when the objective function depends on structural parameters whose values are uncertain. More specifically, they showed how Brainard's classic wisdom that multiplicative uncertainty leads to a cautious policy can be overturned when the loss function weights are not known to the policymakers, and therefore the effects of such uncertainty are taken into account.

B. Data Uncertainty

Central banks need to conduct monetary policy in real time. But the macroeconomic data on variables such as inflation and output, which the central bank policymakers rely on when setting their policy instruments, are typically provided with a considerable lag and are subject to large and extensive revisions. The revision process tends to last for several quarters or years, so it can take a long time before policymakers know the relevant data movements with a sufficient degree of confidence. For instance, since the extent of the revisions in the measurement of the output gap is sometimes considerable, the picture of the state of the economy provided by this statistic at a particular quarter may subsequently be turned upside down. As a result, central banks inevitably face persistent errors in data measurement. This means that not only are the data used in the assessment of the economy incomplete, but policymakers also cannot ascertain the current situation of the economy with certainty.

As discussed earlier, incomplete data can be just another source of additive uncertainty when there are no other types of uncertainty. As in the case of additive shocks, therefore, by the certainty equivalence principle, the optimal policy-making process is typically not affected by “pure” data uncertainty. In other words, the introduction of data uncertainty has no impact on the policy choices (Debelle and Cagliarini, 2000; Jenkins and Longworth, 2002; and others).

However, data uncertainty coming from incomplete data will matter for the policy decision, especially when simple policy rules, such as the (so-called) ‘Taylor rule’ which involves only a small number of variables, are used as a benchmark for policy implementation (see footnote 68 in Chapter 3 for the Taylor rule in detail). This is because

the coefficients attached to those variables may be significantly affected by noisy data, thereby resulting in uncertainty about the coefficients associated with policy rules¹⁹. Consequently, as noted by Orphanides (2003), the certainty equivalence principle ceases to hold in the case of data uncertainty. In effect, the presence of this type of uncertainty can provide a rationale that policymakers ought to respond with greater caution to a variable estimated with error than would otherwise be the case in an optimal policy rule.

For the US economy, Orphanides and van Norden (1999), who examine the reliability of several methods for estimating the output gap in real time, show that taking into consideration the sizeable measurement error derived from these real-time estimates results in a significant deterioration of feasible policy outcomes, causing efficient policies to be less activist. In addition, Orphanides (2001) shows that policy reaction functions estimated from the data actually available to policymakers when policy decisions were made appear quite different from those estimated from data for the same period, revised later. He argues, in particular, that estimated policy rules derived using the *ex-post* revised data instead of real-time data can lead to a misleading description of historical policy. Furthermore, he emphasises that the presence of data uncertainty inevitably leads to biased estimates, and consequently impinges on the relevant specification of the policy reaction functions.

Rudebusch (2001), who attempts to reconcile historical and optimal policy rules of the US economy, finds that data uncertainty (particularly about the output gap) would reduce the coefficient on the output gap in the optimal Taylor rule. Namely, greater output-gap (inflation) uncertainty reduces the output (inflation) response coefficient. This result implies that policymakers are required to attenuate their responsiveness to a noisy variable

¹⁹ Kohn (2007) discusses some of the limitations of simple rules including this limitation.

with error than when there is no data uncertainty.

Aoki (2003) uses a framework of optimising models with nominal price stickiness to examine the issue on how real-time monetary policy should be conducted when there are considerable errors in the measures of inflation and output the central bank uses. His theoretical study concludes that noisy indicators can lead to policy caution and therefore interest-rate smoothing by the central bank is optimal in policy-making. This finding implies that the more poorly real GDP is measured, the less policymakers should respond to changes in GDP when setting their interest rates.

Svensson and Woodford (2003) and Swanson (2004) show that when several indicator variables (*e.g.*, the output gap, output, unemployment and inflation) are used to assess the prevailing economic conditions, increased uncertainty about a specific indicator variable could lead policymakers to react cautiously to a coefficient on that indicator in the optimal policy rule and reversely, to respond more aggressively to the coefficients on other economic indicators. These results are in line with those of Rudebusch (2001) and Orphanides (2001 and 2003).

C. Model Uncertainty

Model uncertainty refers to a lack of knowledge about which model among a given set of alternatives provides the best descriptions of the structural relationships in the economy (Levin *et al.*, 1999). It may be true that uncertainty regarding the structure of the economy is much more fundamental than data uncertainty or parameter uncertainty. There is no common view on the appropriate models for the analysis of monetary policy issues.

Highlighting the importance of uncertainty about the true model in policy-making,

Noyer (2008) states that:

What central banks face today may be seen as a radical kind of *model uncertainty*. Not only are they uncertain about the value of specific parameters, but the probability distributions of target variables and shocks may have changed and standard linear approximations may not be valid anymore. Concretely, this means that they have to make up their mind and set the most appropriate policy considering competing models of the economy (and possibly misspecified models, because of the unprecedented nature of ongoing events). Risk management considerations are then of the essence.

In practice, monetary policymakers need to have a number of alternative models at their disposal for the conduct of monetary policy. It is widely recognised that the best way to deal with model uncertainty is to use multiple models to obtain policy advice (see, for example, Blinder (1998), Engert and Selody (1998), Freedman (1999), Issing (1999), Dennis (2005), among many others). In particular, Blinder (1998), having been active both in central banking and in academia, provides a simple solution to the dilemma of model uncertainty such that:

... Use a wide variety of models and don't ever trust one of them too much. ...
My usual procedure was to simulate policy on as many of these models as possible, throw out the outlier(s), and average the rest to get a point estimate of a dynamic multiplier path. This can be viewed as a rough – make that very rough – approximation to optimal information processing. (1998, pp. 12-13)

As in the case of parameter uncertainty, there are two conflicting implications in

dealing with model uncertainty: conservatism and activism. In the case of model uncertainty, as a whole, much literature contradicts the traditional conservatism principle. Recent analyses, employing the robust control approach²⁰ to monetary policy-making, generally support policymakers' activist response in setting interest rates. For instance, Sargent (1999) and Tetlow and von zur Muehlen (2001), who use robust control methods to analyse the implications of model uncertainty, suggest that monetary policymakers should react more to deviations of actual inflation from its desired level and actual output from its potential than would be the case if this type of uncertainty does not exist. Particularly, Sargent (1999) studies a simple macro-policy model and shows that robustness, in the "robust control" sense, does not necessarily lead to policy attenuation. Instead, the robust policy rule may respond more aggressively to shocks. The intuition for this result is that, by pursuing a more aggressive policy, the central bank can prevent the economy from encountering situations where model misspecification might be especially damaging.

Research results by Stock (1999) and Onatski and Stock (2002) among others bring about a similar conclusion: model uncertainty generally results in a more aggressive response as policymakers seek to avoid the worst-case outcomes.

However, there are some results in favour of conservatism that under model

²⁰ In general, the way to minimise expected losses is a widely used criterion for choosing optimal policy. There are, however, some situations where it may be impossible for policymakers to compute expected losses for different policy choices. This is because they cannot assign probabilities to each of the models. This point necessitates an alternative criterion for policy-making in the face of uncertainty which does not require knowing the probability distribution associated with all potential scenarios. As one line of the literature on policy-making under uncertainty, there is an alternative approach which attempts to search for robust policy rules that minimise expected losses in some worst-case scenarios, within a specified set of possible scenarios; that is, the policy under which the largest possible losses across all potential outcomes is smaller than the largest possible losses under any other policy. A way to pick the optimal policy under this criterion is referred to as the "*robust control approach*."

uncertainty, policymakers should react more cautiously than in the certainty case (Cagliarini and Heath (2000), Tillmann (2009), and others).

Among recent analyses in favour of conservatism, in particular, Tillmann (2009) investigates, using a standard forward-looking monetary model, how the optimal output gap weight in the central bank's objective function can be influenced by the degree of model uncertainty and finds that when the degree of uncertainty increases, the central bank should put a more relative weight on inflation stabilisation. His findings show that the result of Rogoff (1985) – that a central banker, who places a larger weight on inflation stabilisation than the social planner, could be optimal – still holds even under model uncertainty.

Figure 2.2: Implications of Alternative Types of Uncertainty

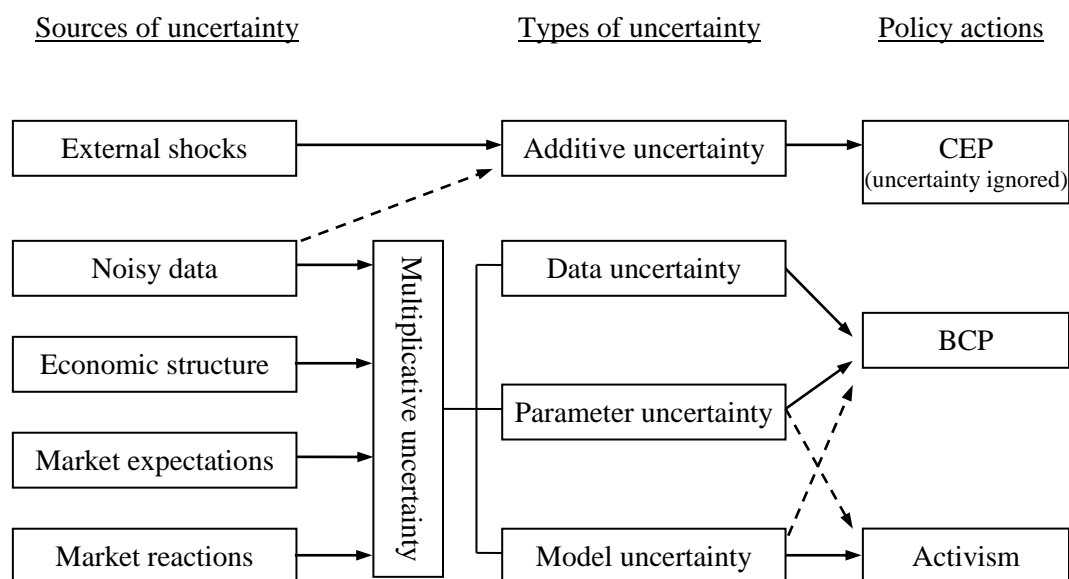


Table 2.2: Research Results on Monetary Policy under Uncertainty

Contributors	Type of uncertainty	Models	Policy stances	Analysis for
Orphanides (2001, 2003)	Data uncertainty	Backward-looking Structural model	Conservatism	Empirics for the US
Rudebusch (2001)	Data uncertainty	Backward-looking Structural model	Conservatism	Empirics for the US
Smets (2002)	Data uncertainty	Backward-looking Structural model	Conservatism	Empirics for the US
Aoki (2003)	Data uncertainty	Forward-looking	Conservatism	Theory
Swanson (2004)	Data uncertainty		Conservatism	Theory
Svensson and Woodford (2003)	Data uncertainty	Forward-looking	Conservatism	Theory
Brainard (1967)	Parameter uncertainty	Static structural model	Conservatism	Theory
Craine (1979)	Parameter uncertainty	Deterministic model	Activism	Theory
Caplin & Leahy (1996)	Parameter uncertainty	Two-player game	Activism	Theory
Svensson (1999a)	Parameter uncertainty	Backward-looking structural model	Conservatism	Theory
Estrella & Mishkin (1999)	Parameter uncertainty	Backward-looking structural model	Conservatism	Empirics for the US
Debelle & Cagliarini (2000)	Parameter (mean) uncertainty	Dynamic model	Conservatism	Empirics for Australia
Sack (2000)	Parameter uncertainty	VAR model, Backward-looking	Conservatism	Empirics for the US
Martin & Salmon (1999)	Parameter uncertainty	VAR model, Backward-looking	Conservatism	Empirics for the UK
Hall et al. (1999)	Parameter uncertainty	Backward-looking structural model	Conservatism	Empirics for the UK
Clarida et al. (1999)	Parameter uncertainty	Forward-looking structural model	Conservatism	Theory
Shuetrim & Thompson (1999)	Parameter uncertainty	Backward-looking structural model	Activism	Empirics for Australia
Svensson (1999a)	Parameter uncertainty	Backward-looking structural model	Conservatism	Theory
Estrella & Mishkin (1999)	Parameter uncertainty	Backward-looking structural model	Conservatism	Empirics for the US
Debelle & Cagliarini (2000)	Parameter (mean) uncertainty	Dynamic model	Conservatism	Empirics for Australia

(continued)

Contributors	Type of uncertainty	Models	Policy stances	Analysis for
Sack (2000)	Parameter uncertainty	VAR model, Backward-looking	Conservatism	Empirics for the US
Martin & Salmon (1999)	Parameter uncertainty	VAR model, Backward-looking	Conservatism	Empirics for the UK
Hall et al. (1999)	Parameter uncertainty	Backward-looking structural model	Conservatism	Empirics for the UK
Clarida et al. (1999)	Parameter uncertainty	Forward-looking structural model	Conservatism	Theory
Shuetrim & Thompson (1999)	Parameter uncertainty	Backward-looking structural model	Activism	Empirics for Australia
Söderström(2000, 2002)	Parameter uncertainty	Dynamic backward-looking	Activism	Empirics for the US
Hansen & Sargent (2008)	Parameter uncertainty	Backward-looking structural model	Activism	Theory
Stock (1999)	Parameter uncertainty	Backward-looking structural model	Activism	Theory
Giannoni (2002, 2007)	Parameter uncertainty	Forward-looking model	Activism	Theory
Onatski & Stock (2002)	Parameter uncertainty	Backward-looking structural model	Activism	Theory
Levin & Williams (2003)	Parameter uncertainty	Three-macro model	Activism	Empirics for the US
Kimura & Kurozumi (2007)	Parameter uncertainty	Dynamic forward-looking model	Activism	Theory
Tillman (2009)	Model uncertainty	Forward-looking model	Conservatism	Empirics for the US
Tellow & von zur Muehlen (2001)	Model uncertainty	Forward-looking model	Activism	Empirics for the US

2.3 Asset Prices and Monetary Policy

This section reviews previous literature on relationships between asset prices and monetary policy. And, it also discusses the importance of asset prices in light of the conduct of monetary policy. The section examines, in particular, the linkages between asset prices and financial stability after the GFC of 2007–2009 and their implications for monetary policy.

2.3.1 The Implications of Asset Prices on Monetary Policy

2.3.1.1 Do Asset Prices Matter?

Traditionally, most central banks have implemented their policies to attain the twin goals of *monetary stability* and *financial stability*. Implications of asset prices with respect to the attainment of each goal, can be divided into the following two categories: first, the *ex-ante* meaning of asset prices, in light of *monetary stability*, includes an expected inflation which refers to information about the inflation outlook, and its *ex-post facto* implication is that changes in asset prices take place prior to inflation inasmuch as they affect inflation through a variety of channels such as wealth effects; second, in terms of *financial stability*, irrespective of the implication of asset prices on monetary stability, if changes in asset prices along with credit expansion deviate from a proper level reflecting real economic conditions for a long time and bubbles are formed, simultaneous defaults of corporate and financial sectors in the process of asset price booms and busts might result in severe problems like economic recession or debt deflation.

2.3.1.2 Price Stability and the Role of Asset Prices

Asset prices are fundamentally forward-looking.²¹ As a result, they contain information about expected future inflation. This information is potentially important for monetary policymakers, especially in the context of an inflation targeting (IT) regime in which

²¹ An asset is something that gives a holder a flow of cash or services in the future. This seems unobjectionable enough. In this chapter, however, asset prices refer largely to the prices of residential property (private houses) and equities. Since the assets we weigh for the attainment of the central bank's goal (*e.g.*, financial stability) are mainly house property and equities, the prices of assets such as bonds, derivatives and foreign currencies are not considered in this subsection.

future inflationary pressures need to be monitored and if necessary, offset. This implies that asset prices can be effectively used as an intermediate target or as a source of information on future inflationary pressures.

The discussion over the precedence of asset prices to future inflation tends to mainly focus on two arguments: expected inflation information that asset prices convey; and monetary transmission channels from asset prices to inflation or real economic activity.

A. Information on Inflation Expectations

The evaluation of asset prices, which is determined by the present value of future income generated from those assets, reflects the inflation expectations that economic agents form. Hence, changes in inflation expectations can be inferred from the evolution of asset prices. Also, inflation expectations of economic agents pose self-fulfilling characteristics in that they affect future inflation levels by influencing the setting of nominal wages and commodity prices. Accordingly, a large portion of future paths of inflation can be predicted on the basis of the movements in expected future inflation.

The evidence suggests that information on expected future inflation derived from the bond market is relatively reliable with respect to inflation expectations (especially compared to that derived from other assets such as housing and stocks). For instance, Mishkin (1990a,b), BIS (1998) and others evaluate the changes in expected inflation based on the spread between long-term and short-term interest rates. The results differ from country to country and time periods, but the spread is generally reported as effective in predicting future inflation.

In contrast to bonds, for other assets such as house property and stocks, the income

flows after expiry are unclear. Accordingly, even though real interest rates in the markets are the same over the entire period, those asset prices tend to be largely affected not only by expected inflation for the corresponding period but also by other economic and non-economic factors when the flow of income is converted into the current value. For these reasons, some argue that it is difficult to effectively extract information about expectations from house or equity prices unlike the bonds.

B. Monetary Transmission Channels from Asset Prices to Inflation

Booms and busts in asset prices affect the economic activities of households, firms and financial institutions through a variety of monetary transmission channels, all of which eventually influence the evolution of prices, *i.e.*, inflation. The wide spectrum of the monetary policy transmission mechanisms can be classified into three different channels: a demand channel; a cost channel; and an inflation expectation channel (see Mishkin, 1995 and 2001; Goodhart and Hofmann, 2000; IMF, 2000 and 2008; and Bank of England, 2003). This subsection will provide an extensive overview of monetary transmission channels discussed in the existing literature.

(Demand Channel)

A demand channel refers to the effect through which changes in asset prices via the movements of consumption and investment lead to a change in excess demand, thereby finally affecting inflation. This channel can be further split into three sub-channels: the asset-price channel; the balance-sheet channel; and the signalling effect channel.

First of all, the monetary policy actions are transmitted to the real economic activities through movements in prices of assets such as stocks, bonds and residential

housing. In this *asset-price channel*, wealth effects and the Tobin's Q theory (Tobin, 1969) provide important mechanisms for how asset-price fluctuations can have an impact on individuals' consumption and firms' investment choices, respectively. According to the life cycle and permanent income hypothesis²², if the values of their home or stock portfolios they hold rise due to escalating prices, consumers may feel richer, resulting in an increase in consumer spending, due to the fact that consumers tend to smooth their consumption throughout their lifetime (consumption smoothing). This is known as the household's wealth effects on consumption. Regarding Tobin's Q theory²³, when equity prices go up, the market valuation of a firm's stock becomes greater than its equity book valuation, which means that as Tobin's Q rises, so will the firm's investment.

Second, a rise in asset prices can improve banks' and firms' *balance sheets*, which enable economic agents to borrow more from financial institutions: not only does the lending capacity of financial institutions improve, but the value of collateral, which households and firms can provide, also grows. That is, when asset prices rise, economic agents go through a self-sustaining process which continuously expands the credit supply of financial institutions via the increase of collateral values (Davis, 1995; Ham and Hong, 2002). On the other hand, however, a sudden plunge in asset prices leads the net asset valuation of the debtor to dwindle, giving rise to moral hazard and adverse selection problems owing to lack of information. Under such circumstances, financial institutions reduce the credit supply itself rather than applying a lower interest rate in accordance

²² See Modigliani (1966, 1971) and Deaton (1992) for a more detailed exposition of the life-cycle and permanent income hypotheses.

²³ Tobin's Q can be defined as the ratio of market value of firms to the cost of acquiring new capital. See for example, Mishkin (1995) and IMF (2000) for a more detailed explanation.

with the change in credit standing. This channel places emphasis on financial market imperfections, which arise from asymmetric or incomplete information in the credit market (see, for example, Stein, 1995; Bernanke and Blinder, 1988; and Bernanke and Gertler, 1995).

The last sub-channel is a *signalling effect channel*, which stresses the potential role of current asset prices over future economic predictions. Aggregate demand in the economy in any given period can be affected by people's expectations about their future incomes and profits. The developments of real asset prices, which are closely related to real economic activities, have an effect on such expectations by signalling economic outlook including the growth of real incomes in the future. Consequently, this signal may affect current firms' investment and households' consumption expenditures in the economy.²⁴

(Cost Channel)

The cost channel of monetary transmission emphasises supply-side effects of asset-price movements on the inflation process. Increases in the prices of real estate such as houses and land, which are used as inputs in the production process, have an impact on production costs. As a result, firms tend to raise producer prices of goods and services. Firms' production costs are attributable to rises in rent for land and plants or to increases in wages due to employee demands for higher payments to meet increases in housing expenditure. These changes in turn lead to inflation in the economy.

(Inflation Expectation Channel)

²⁴ Empirical evidence that stock prices influence consumption is provided in Poterba and Samwick (1995) and Otoo (1999).

The inflation expectation channel is based on the importance of the formation of expectations or confidence on the part of the forward-looking agents. Any changes in asset prices can affect aggregate economic activity and inflation through households' and firms' expectations about the future course of the economy. In particular, rises in inflation expectations owing to escalating asset prices have an influence on the process of firms' wages and price setting, thereby deciding on future expected labour income, and profits and costs, as a result of which aggregate demand grows in the economy. Also, growing demand in turn ultimately causes general price levels to escalate.²⁵

2.3.1.3 Financial Stability and the Role of Asset Prices

A. What is Financial Stability?

In general, a quantitative definition, based on specific indicators, for instance, the consumer price index (CPI), can be applied in the case of *price stability*. However, such a quantitative definition is hard to be applied to the concept of *financial stability*. Accordingly, a variety of views have been presented with respect to the definition of financial stability.

Crockett (1997) takes financial stability to apply to both the key institutions and markets which constitute the financial system. Stability in financial institutions refers to a situation where individual financial institutions are capable of maintaining normal business activities without any intervention or support by the authorities, and market participants trust such financial institutions. Similarly, stability in financial markets means a situation where economic fundamentals are duly reflected in price variables,

²⁵ See, for example, BOE (2003) and ECB (2000) for more detailed exposition of inflation expectations.

such as interest rates, stock prices and exchange rates, formed in the financial markets. The price variables, as a result, do not vary substantially as far as there are no changes in economic fundamentals.

Goodfriend (1987) and Cukierman (1991) present less conceptually, but more directly observable definitions that financial stability is a state where no banking crisis exists and asset prices including interest rates are relatively stable compared to some reference prices.

In the meantime, some attempt has been made to define financial *instability* instead of its positive counterpart, financial *stability*, because it is convenient and useful to do so. In other words, by describing financial instability, they define financial stability as exactly its opposite state. For example, Mishkin (1997 and 1999) describes financial instability as a state in which the financial system does not perform its role well in channeling funds to economic agents with productive investment opportunities, and thereby the economy cannot operate efficiently. This definition emphasises the intermediation function of the financial system in supplying credit to the real sector, and stresses the role of asymmetric information in causing financial instability. Similarly, Ferguson (2002) defines financial instability as a situation where some important financial asset prices rapidly diverge from fundamentals, and/or a situation in which aggregate demand significantly deviates from the potential capacity of an economy as the market functioning and credit availability are rapidly distorted both domestically and internationally.

Issing (2003) argues that the role of central banks for financial stability and trade-offs between price stability and financial stability differ in accordance with how we

define financial stability. For example, the definition of financial stability from a systemic perspective highlights prudential supervision as a way of achieving financial stability, and therefore the trade-offs do not always exist between financial and price stability. In such a case, the best outcome can be derived when price and financial stability are achieved with different measures, respectively. But, a short-term trade-off can appear between price and financial stability when the latter is defined in consideration of the stability in asset prices such as house prices and stock prices; thereby creating room for the central bank to make some contributions to the pursuit of financial stability. However, he points out the problem that moral hazard can occur if the central bank manages monetary policy with an objective of affecting asset-price levels, insisting that the central bank should monitor changes in asset prices rather than their levels while paying attention to how such changes influence the overall economic system.²⁶

To sum up, financial stability can be defined as a state where financial institutions carry out a financial intermediary function smoothly while price variables in the financial market move stably, reflecting economic fundamentals.

B. Why does Financial Stability Matter?

Apart from protecting inflationary pressure risks, which is traditionally their best-known function, central banks, in recent years, recognise asset-price volatility as a bigger risk in terms of financial stability, particularly when asset prices fail to reflect

²⁶ Responding to asset prices itself or establishing mechanical policy reactions by targeting the asset-price level may result in moral hazard problems because it might promote risk-taking behaviour by private agents in anticipation of the asset price stabilising attempts of monetary policy (Trichet, 2005; ECB, 2005).

underlying economic conditions such as faster productivity or lower interest rates, and excessively rise to generate a bubble²⁷. The first reason why central banks weigh asset-price volatility is that for asymmetric issues of asset-price shocks, the degree of the negative effect arising from the collapse in asset prices after bubble booms and busts is much bigger than that of the positive effect caused by rising asset prices. Large falls in asset prices lead to a reversal of the feedback loop in which lenders diminish credit supply, the demand for assets decreases further, and asset prices accordingly fall even further. These changes can put the stability of financial systems at risk, thereby causing severe harm to real economic activity (Hessius, 1999; Mishkin, 2008).

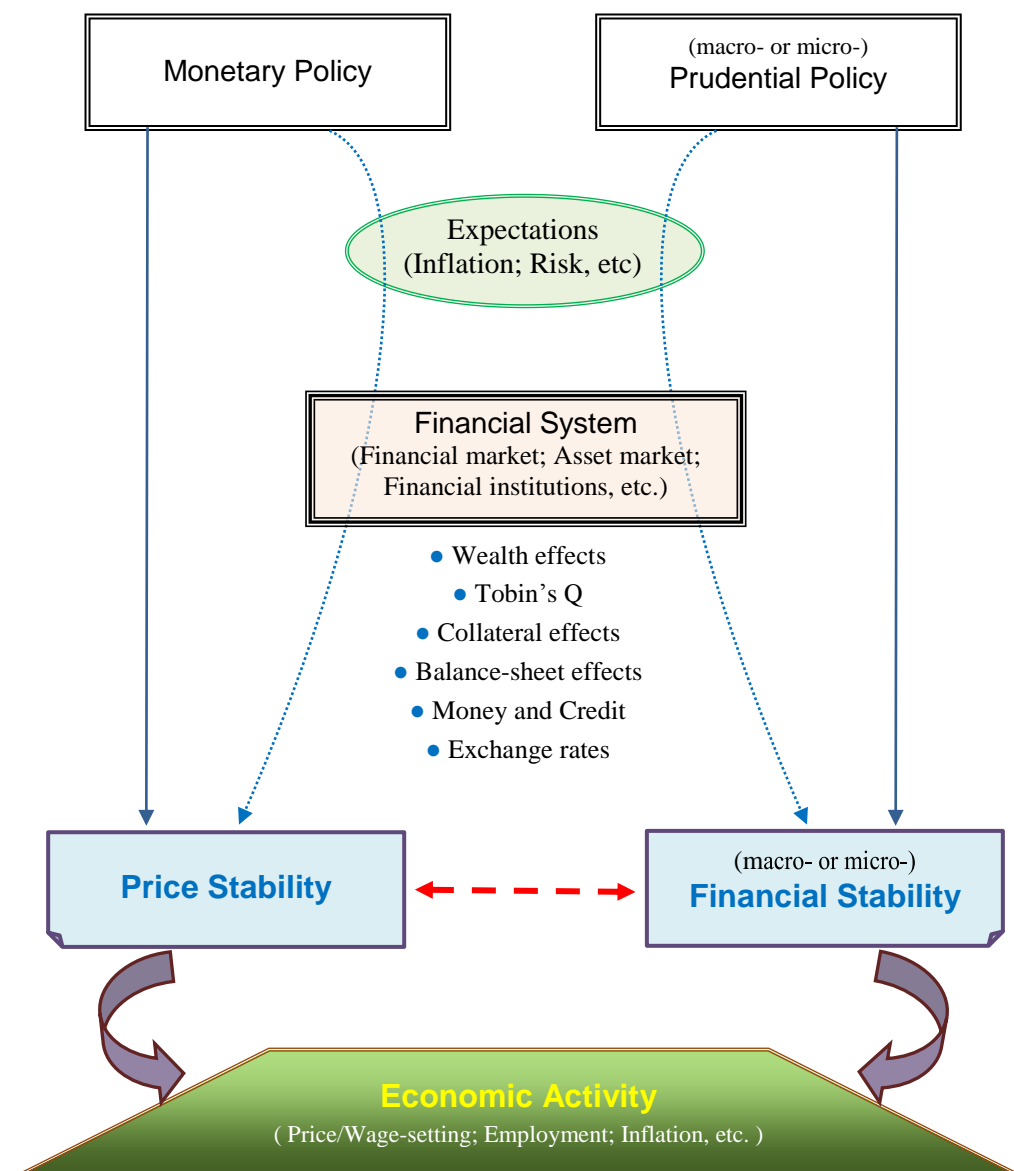
The second reason is that price stability does not necessarily guarantee financial stability. Asset-price bubbles can form even in a low and stable environment in which bank credit can expand gradually over time (Goodhart, 2013; Park, 2011)²⁸. Especially, under an IT regime utilising interest-rate management, the logic for pre-emptively adjusting the interest rate upward is very weak when inflation remains subdued. This means that central banks are subject to some constraints in keeping any excessive credit expansion under control. Moreover, financial instability caused by increased asset-price volatility may threaten price stability by aggravating the environment for operating monetary policy. Hence, most central banks have recently placed more importance on achieving financial stability through credit management as well as asset-price stabilisation rather than price stability when carrying out their policies.

²⁷ The term, ‘bubble’ is often referred to interchangeably as ‘misalignments’ meaning that actual asset values are significantly deviated from their fundamental values.

²⁸ A good recent episode is the GFC following the Lehman Brothers collapse in 2008. Note that this crisis showed that even under low and stable inflation, imbalances such as wide swings in asset prices can occur, and that this can cause financial instability.

Figure 2.3 summarises the above discussion, demonstrating the monetary transmission mechanism with macro- or micro-prudential policy. For simplicity, this figure does not display all inter-linkages including feedback effects and additional interactions between variables.

Figure 2.3 The Monetary Transmission Mechanism with Prudential Policy



2.3.2 The Debate on the Monetary Policy Responses to Asset Prices

In the previous section, we discussed the importance of asset prices in light of the conduct of monetary policy. In the meantime, most central banks have the same view in that they should pay more attention to asset-price changes, but have different ideas on how to react to fluctuations in asset prices. At the risk of oversimplifying, possible policy responses may be split into *direct* responses and *indirect* responses in accordance with the adequacy and the degree of policy reactions.

Before the GFC of 2007-2009, a prevailing view was that central banks should restrain from directly reacting to asset prices *per se* until their changes visibly put pressure on general prices. Recently, however, asset prices have been fluctuating under low and stable inflation conditions. Thus, a number of academics and central bankers have started to recognise some structural limitation of the pre-crisis approach for monetary policy, and many of them insist that central banks need to take more active measures against asset-price fluctuations.

2.3.2.1 Indirect Responses to Asset Prices: the pre-crisis view

An indirect response to asset-price changes, which is labelled as the *conventional view* or the *benign neglect approach* among economists and central bankers, refers to a strategy in which central banks should place an emphasis exclusively on stabilising the prices and real activity in the economy, and as a result they should not react directly to asset-price movements *per se*. In other words, policymakers should respond to asset prices only insofar as they surely signal future changes in expected inflation and real economic activity (see, Smet, 1997; Bernanke and Gertler, 1999; Batini and Nelson, 2000; and

Greenspan, 2002). As Kohn (2006) stated, keeping this strategy does not mean that central banks ignore the expected future dynamics of speculative activity. When central banks suspect that an asset bubble seems likely to build up for a time before bursting, they need to take some actions in advance considering the future evolutions of inflation and output.

This conventional view reflects central banks' concern that economic instability may be generated when they directly react to asset-price misalignments. There are three reasons for this view: the first reason is that there may be doubts about central banks' ability to identify asset-price bubbles and their ability to act at just the right time to curb the rise in asset prices without causing a rapid decline in asset prices (Plosser, 2007). In particular, it is difficult to disentangle the expectational factor of the price from the objective valuation of the asset, due to the fact that asset price determinants depend on each market participant's subjective expectations of uncertain magnitudes of the future course of the asset markets or economic developments (ECB, 2005). Central bank policymakers are not always any better than market participants in determining whether asset prices reflect economic fundamentals, so they cannot at times identify misalignments in the prices of assets such as house property and equities with certainty. In particular, Mishkin (2008) argues that when monetary policymakers are uncertain about the presence or extent of bubbles, their actions to impact asset prices can interfere with the role of asset prices in allocating resources²⁹.

Secondly, even though asset-price misalignments could be identified, the effect of interest-rate adjustment in curtailing them is highly uncertain and can be, in an

²⁹ See, for example, Bernanke (2002) for a discussion of this potential problem.

unexpected direction, propagated to the overall economy as well as a particular class of asset market (Mishkin, 2008). For example, pre-emptively raising policy rates to cut off a rapid rise in house prices is likely to impact other asset markets such as the stock market, not just the escalating housing market. As Bernanke (2002) stated, monetary policy might be far too blunt a tool for effective use against asset bubbles: central banks do not have the fine policy tools to cut out the bubbles alone.

Thirdly, it is also argued that after the collapse of asset market bubbles, a decisive easing (or expansionary) reaction of monetary policy would be sufficient enough to avoid any subsequent negative effects on the financial system and the real economy. Hence, central banks should be simply prepared to vigorously interfere with asset markets by cutting policy interest rates right after the bursting of the bubble in order to sustain real economic activity and minimise the potential probability of deflation (Smaghi, 2009).

The most important criticism for this *conventional view* is whether such indirect responses can provide a guarantee of financial stability under the current monetary operating system. Regarding this issue, Bernanke and Gertler (1999) argue that a policy goal in normal times, *price stability*, and a policy goal in times of financial stress, *financial stability* can be pursued within a unified framework which is a regime of *flexible IT*. A key strength of this framework is that it enables central banks to automatically adjust interest rates in a stabilising direction in the face of asset market imbalances. Moreover, the flexible IT that strongly focuses on stabilising aggregate demand and inflation will appear to result in “leaning against the wind” to the extent that increases in asset prices will act as a spur to aggregate demand, and *vice versa* for declines in asset prices.

2.3.2.2 Direct Responses to Asset Prices: the *recent* consensus view

In contrast to early arguments that were often posited in general skepticism about both the feasibility and the desirability of the pre-emptive policy strategy, many central bankers and economists now argue that monetary policy should aim to do more than just respond to current and expected developments in asset prices, inflation and the output.

The point of the approach of directly responding to asset-price changes is that even if the effect of asset-price movements on inflation, via changes in aggregate demand, is insignificant and uncertain, central banks should take a much tighter policy stance in the face of rising asset markets to preclude any potential bubble creation. This pro-active strategy reflects the following arguments: changes in asset prices may affect aggregate demand but may not lead to rising inflation in the future because of aggregate supply-side factors like productivity enhancement; moreover, even if they cause inflation, any inflationary pressures may not be fully taken into consideration when conducting monetary policy due to the limitation of methods to measure inflation levels. In these circumstances, if central banks selectively react to only information regarding inflationary pressures, financial market stabilisation cannot be achieved due to a possible delay in implementing monetary policy, especially during the asset-price bubble period.

Kent and Lowe (1997)³⁰ come out in favour of a way to pre-emptively respond in the incipient stage of bubble formation, while Cecchetti *et al.* (2000) maintain that when asset prices deviate from their underlying fundamentals and when bubbles continue to be created, central banks should intervene in the movements of asset prices by interpreting

³⁰ They set up a model where monetary policy choices can impact the evolution of a bubble. Their analysis is based on a one-shot bubble that never arises again after it bursts. They show that the monetary authority has an incentive to prick the bubble in the face of an initial boom-phase stage.

information implied in the bubbles rather than automatically responding to all the changes in asset prices³¹. In the meantime, Blanchard (2000) advocates that central banks conduct rather active aggregate demand management policies; they should tighten monetary policy during the bubble-formation period more than is suggested by inflation targeting (IT), and they should loosen it in the opposite circumstances, considering the so-called ‘composition effect’, meaning that asset-price bubbles have a relatively bigger impact on investment than on consumption. The problem here lies in how central banks can pre-emptively detect bubbles that are formed when asset prices deviate greatly from economic fundamentals, and then how they can effectively cope with those bubbles through policy actions such as interest-rate adjustment.

The extreme view with respect to the important role of asset prices in the conduct of monetary policy is to include asset prices directly in the price index defining the policy objective, as is suggested notably in Alchian and Klein (1973). The basic idea is that from a welfare perspective central banks should care about stable prices not only of current but also future consumer goods by focusing on a cost-of-life index. Price indices, such as the CPI or GDP deflator, are deficient in that they consider only the price of goods consumed *today*. A complete measure of the living cost would also contain changes in the prices of *future* goods. Asset prices reflect the current money prices of claims on future as well as current consumption. In short, asset price today can be a reasonable proxy for future prices of consumer goods. In a similar vein, Goodhart (1995)

³¹ Cecchetti *et al.* (2003) are cautious in arguing whether monetary policy should target asset prices or not. They state that “we are *not* advocating that asset prices should be *targets* for monetary policy, neither in the conventional sense that they belong in the objective function of the central bank, nor in the sense that they should be included in the inflation measure targeted by monetary authorities” (p. 429).

also highlights the need to take the movements of asset prices into account in the setting of monetary policy. More recently, Smaghi (2009) and Allen and Rogoff (2010) argue that asset prices such as real estate prices should be taken into account when implementing monetary policy, pointing out some limitation of the pre-crisis view that central banks should not directly intervene in the movements of asset prices until they visibly put pressure on general prices.

2.4 Conclusion

This chapter has reviewed the existing literature dealing with two important issues confronted by central banks in the conduct of monetary policy.

The first issue is about monetary policy under uncertainty. Central bank policymakers are faced with different types of uncertainty, and each type has unique implications for monetary policy-making. Additive uncertainty, such as uncertainty associated with possible shocks in exogenous variables, does not cause a serious problem for policymakers inasmuch as optimal policy responses in the presence of this type of uncertainty are identical to the certainty case: under additive uncertainty, when a standard linear-quadratic framework is assumed and the economic structure could be known to monetary policymakers, then *certainty equivalence* implies that uncertainty regarding the future time paths of shocks would not affect the policy-decision choices.

In contrast, multiplicative uncertainty — for example, uncertainty about the state of the economy (*data uncertainty*) or the strength of economic relationships (*parameter uncertainty*) — justifies the need for a cautious approach to changes in central banks' key

policy rate. But, even within one category of uncertainty, it is often difficult to draw clear conclusions for policy-making since policy prescriptions can be different depending on the employed methodologies or models. Nonetheless, we can obtain one important implication from the literature: uncertainty should be taken into account when policy-decisions pertaining to interest rates are made. Many studies which derive the optimal interest rate rule considering uncertainty about parameters or data draw conclusions that the central bank's conservative policy stance is more appropriate. However, previous studies on model uncertainty insist that an aggressive policy stance is more desirable. All in all, monetary policy gradualism would seem to be frequently observed and sensible in the real world. However, central banks should confront the challenges such as the more accurate recognition of uncertainty and the timely implementation of policy, in order to navigate, as best they can, through evolving uncertainty.

Turning to the second issue, this chapter has discussed the relationships between asset prices and monetary policy, and it has reviewed how central banks should react to the movements in asset prices. The GFC of 2007–2009 has led to a rethinking of how central banks react to possible asset-price bubbles. A review of the literature indicates that volatile fluctuations in asset prices can pose severe risks to the real economy, especially when they are accompanied by financial instability. Accordingly, a number of economists and central bankers argue that uncertainty and the challenges faced by central banks in dealing with asset prices cannot be grounds for policymakers just looking on without doing anything, notwithstanding the fact that it is hard to detect bubbles in real time, particularly in their nascent stages. Many of these advocates, for example, Smaghi (2009) and Allen and Rogoff (2011), have pointed out some limitation of the

conventional view that central banks should not directly react to the movements in asset prices until they visibly lead to pressures on general prices. Thus, they insist that central banks need to take more active measures against asset-price fluctuations, since asset prices can fluctuate in low and stable inflation conditions, so as to minimise the risk of economic weakness and financial instability. There is a need for further theoretical and empirical research to be conducted in order to reach a convincing conclusion to this issue.

Chapter 3

Monetary Policy in Korea: a Framework, Uncertainty and Interest-rate Smoothing

3.1 Introduction

From the early 1990s, price stability became one of the most important goals of central banks in many countries. Central banks, however, found the traditional approach — namely, influencing inflation and output by controlling intermediate target variables, such as broad monetary aggregates, to achieve their ultimate goals of low inflation and sustainable growth — inadequate or not uniformly successful. The main reason is that in the 1980s, rapid financial innovation and liberalization with the accordingly increased complexity of new instruments and explosive growth in the volume of financial transactions, obscured distinctions between monetary aggregates and thus destabilised the relationship between the monetary aggregates and ultimate policy goals, resulting in a reduction in the efficacy of this method of conducting monetary policy (Oh, 2000).

In order to address this problem, several advanced countries — New Zealand (1990), Canada (1991), the UK (1992), Sweden (1993) and Australia (1993) — adopted an inflation targeting (IT) regime with an explicit objective. Other advanced countries that later joined the group of inflation targeters are Israel (1997), Iceland and Norway (both, 2001). From the late 1990s, a large number of emerging markets and developing countries adopted the framework.³² In the wake of the 1997-1998 Asian Financial Crisis, Korea was among a number of emerging market economies (EMEs) that adopted an IT regime as its framework for the operation of monetary policy. The complete transition to a full-fledged IT (or a pure IT) regime in Korea was made in 2001, when the monetary indicator, M3, was no longer set as an intermediate target.

Regarding the choice between an interest rate and a monetary aggregate as the central bank's policy instrument, Poole (1970)'s classic analysis provides a simple but instructive solution, explaining the policy instrument shift from monetary aggregates to interest rates mentioned above. The basic message from his conclusion implies that growing volatility in the financial sector (money demand or money multiplier shocks) increases the desirability of an interest rate policy procedure over a monetary aggregate procedure.³³

With the adoption of an IT regime, many central banks switched their framework

³² These IT frameworks basically operate under officially flexible exchange rate regimes. As of the end of March 2010, 26 countries use an inflation targeting, about half of them emerging market or low-income countries. Moreover, several central banks in more developed countries, including the European Central Bank (ECB), the Federal Reserve Board in the United States, the Swiss National Bank, and the Bank of Japan, have adopted many of the main elements of inflation targeting. See Roger *et al.* (2009) and Roger (2010).

³³ Poole (1970) argues that under the assumption that the policy objective is to stabilise real output, greater output stability can be achieved by adjusting interest rates when money demand is highly unstable and difficult to predict over a short period of time. See Walsh (2010) for a summary of Poole's conclusion on the choice of monetary policy instrument.

from monetary aggregate-oriented operations to interest rate-oriented. In other words, inflation targeting central banks, in general, use the short-term interest rate as their policy instrument (or an operating target), not monetary aggregates such as M2.³⁴ Under this interest rate-oriented monetary policy framework, central banks are required to make decisions on the size, timing and speed of adjustment of policy rates as well as judgement on whether to change their policy stance. In conducting this IT strategy, central banks are faced with considerable uncertainty regarding both the economic outlook and the impact of their policy instrument (*i.e.*, the short-term nominal interest rate) on inflation and real economic activity.

In the presence of uncertainty, some specific patterns in policy interest rate path are found in Korea as in most advanced countries: infrequent changes in policy interest rates; successive changes of the interest rates in the same direction; asymmetric adjustments in terms of the size of interest-rate changes for continuation and reversal periods; and a long pause before reversals in policy interest rates.

This chapter will provide an analytic overview as to the objectives that the Bank of Korea (BOK) has sought to achieve, and on how the monetary policy framework in Korea has changed, since its establishment in 1950. We will also discuss interest-rate smoothing, and in the light of this discussion, present several stylised facts on the path of the policy interest rate using Korean data. In this chapter, we take the position that interest-rate smoothing is an appropriate result for developments in macroeconomic

³⁴ Of course, non-IT countries, for example, the US, Japan and Switzerland, also use interest rates as policy instruments. However, the essential distinction between inflation and monetary targeting rests on which indicator central banks use as a policy instrument: under a monetary targeting regime, monetary policy is conducted by making use of an intermediate monetary growth target and employing reserve money as the operating target to attain it, unlike IT countries which use an interest rate as the operating target.

conditions, especially in today's highly integrated global environment. Such an environment inevitably poses difficulties for central bank policy-making: policymakers are constantly faced with an ever greater degree of uncertainty when determining the policy interest rate.

The remainder of this chapter is structured as follows. In Section 3.2, the objectives of monetary policy will be discussed. Section 3.3 reviews developments of the monetary policy framework in Korea, which has evolved from a monetary targeting to a (full-fledged) inflation targeting regime. In the same section, we also attempt to identify monetary policy shocks and uncertainties in the actual conduct of monetary policy. Section 3.4 investigates the characteristics of policy-rate movements, including stylised facts and the degree of interest-rate smoothing. This section also provides a theoretical derivation of the policy reaction function with a partial adjustment term, and examines the degree of interest-rate smoothing in Korea through empirical analyses using OLS and GMM estimations, and discusses why central banks smooth interest-rates. Finally, Section 3.5 concludes.

3.2 What are the Objectives of Monetary Policy?

3.2.1 Price Stability

The objectives of monetary policy have varied over time according to the economic situation of a country, but it is nowadays usually agreed that monetary policy should pursue *price stability*³⁵ as the most important objective. As with the majority of central

³⁵ Under the gold standard system, central banks in many countries stressed *equilibrium in the balance of payments* since large disequilibria often arose from the inflow and outflow of gold as a result of trade with other countries. Beginning in the early 1930s, many countries, hit by the Great Depression, adopted a fiat currency or managed monetary system. Subsequently, removing the possibility of monetary laxity and stabilising prices came to be

banks, the BOK's primary objective in its monetary policy is *price stability*.³⁶ Price stability is often referred to interchangeably as *monetary* stability (Issing, 2003). A generally accepted definition of price stability is one where the general level of prices in the economy is stable or the level of inflation is low (Selody, 1990; Crockett, 1997; Svensson, 1999b).

This objective reflects the view that sustainable economic growth cannot be achieved without price stability. High inflation has sizeable adverse consequences for the real economy. Inflation is a source of uncertainty that makes economic decision-making more difficult. In periods of high inflation, relative prices and wages become more variable. High and variable inflation can generate uncertainty because people become confused about what the appropriate price for each good is, and about how quickly the general price level is rising. Uncertainty in turn makes the price system less efficient as a mechanism for the allocation of income and resources, leading to a decline in economic efficiency.

In Korea, during the period³⁷ from 1965 throughout the 1970s, the annual rate of increase as measured by the consumer price index (CPI) reached around 14 percent. But, in the 1980s the annual rate of CPI inflation dropped to single-digits thanks mainly to economic stabilisation policies. In the 1990s, this pattern was on the whole maintained except for the year 1998³⁸. In the early 2000s, the CPI inflation rate moved more stably

seen as one of the important goals of monetary policy. In particular, with the global economy suffering from inflation owing to the two oil crises in the 1970s, this view became widely accepted. See BOK (2008b) for a more detailed explanation.

³⁶ The current Bank of Korea Act clarifies that the Bank proclaims price stability as the purpose of the Bank of Korea's establishment, and stipulates that it should seek to achieve price stability by setting an inflation target in consultation with the government and do its utmost to attain this target.

³⁷ In Korea, this period is dubbed the *era of economic development* in view of the rapid growth rate.

³⁸ At that time, consumer prices rose rapidly due to the Korean won's depreciation against major currencies following the 1997–1998 Korean currency crisis.

within a range of 2~3 percent. From early 2008, however, it accelerated again due to a sharp rise in international commodity prices such as those for crude oil and cereals.

It is widely agreed that a small positive inflation rate is more desirable than zero inflation. Frequently the argument has been made that even though price stability is important for economic growth, inflation is to some extent unavoidable mainly because of structural problems such as wage stickiness in the form of sticky-wage contract practices (Tobin, 1972 and Akerlof *et al.*, 1996); and that reining in inflation too tightly may come at a high cost; for example, the weakening of growth momentum.

In addition, it is well known that most price indices do not properly reflect shifts in demand to substitutes caused by price changes, or qualitative improvement in goods due to technological advances. As a result, the inflation rate measured by a specific index, for example, the CPI, may be overestimated, which is called an ‘upward bias’ in the measurement of the consumer price index³⁹. In this case, if the targeted rate of inflation is set as zero percent, actual deflation may occur. Proponents favouring mildly positive inflation, therefore, argue that price rises within a certain range should be accepted.

However, even though a certain mildly positive inflation rate is desirable, there is no consensus as to what the optimal rate of inflation should be. In fact, the optimal rate of inflation is dependent on country-specific factors, such as each country’s economic structure, previous inflation experience, and sociopolitical environment. The UK and Canada regard inflation of 2 percent as price stability; New Zealand takes 1~3 percent; and the European Central Bank, in a more explicit way, defines price stability as inflation of ‘below, but close to, 2 percent’ which is to be maintained over the medium term (ECB, 2004).

³⁹ For further details, see IMF (1999).

Compared to these countries, emerging market countries that operate an IT regime tend to regard a somewhat higher level of inflation as indicative of price stability: for example, Brazil and Indonesia take 4.5 percent; South Africa 3~6 percent; and Korea and Chile 3 percent.

3.2.2 Financial Stability

Another policy objective that central banks nowadays strive to attain is *financial stability*. This is because financial development and stability are essential constituents of sustainable economic growth. In contrast to the case of price stability, concerning which a greater degree of consensus has been reached, no generally accepted definition of financial stability has yet been provided.

Even though there has been no general consensus on the best definition of financial stability, many have cited Crockett (1997)'s definition: financial stability broadly rests upon the stability of the key financial institutions and markets which constitute the financial system⁴⁰.

Financial stability is often defined in terms of its antithesis, *i.e., financial instability*. As discussed in Chapter 2, Mishkin (1997 and 1999) defines financial instability as a situation where the financial system does not work well in supplying funds to economic agents who have productive investment opportunities, and as a result the economy cannot operate efficiently. In this definition, the intermediation function of the financial system

⁴⁰ This requires (i) that the key *institutions* in the financial system are stable, in that there is a high degree of confidence that they can continue to meet their contractual obligations without interruption or outside assistance; and (ii) that the key *markets* are stable, in that participants can confidently transact in them at prices that reflect fundamental forces and that do not vary substantially over short periods when there have been no changes in fundamentals (Crockett, 1997).

is emphasised in terms of supplying credit to the real sector, and moreover, the role of asymmetric information is weighed with respect to financial instability. In a similar way, Ferguson (2002) defines financial stability with reference to its absence, *i.e.*, financial instability. According to him, financial instability refers to a situation where the prices of some important financial assets diverge rapidly from fundamentals, and/or a situation in which aggregate demand significantly deviates from the potential capacity of an economy as market functioning and credit availability are distorted.

Financial instability can trigger severe economic crises⁴¹, while a stable financial system enhances the efficiency of the distribution of resources and thus boosts economic development. In general, financial instability tends to be accompanied by a serious credit squeeze. To cope with this situation, the central bank uses its exclusive power to issue paper money and to quickly supply the necessary funds to financial markets.⁴² When a serious liquidity crisis breaks out in the economy, the central bank attempts to prevent a string of bankruptcies by supplying the necessary liquidity to financial institutions which are in trouble. Furthermore, to the extent that the effects of monetary policy are transmitted to economic activities and prices through the financial sector, the transmission channel of monetary policy will not work appropriately when financial markets do not function properly or suffer from instability. Consequently, the monetary policy will not have as much effect on the economy as expected. For this reason, the BOK has viewed financial stability as an important policy objective and has paid great

⁴¹ Since the early 1980s, as the volume of financial transactions has grown and the integration of capital market has increased, institutions in the financial sector have become more interdependent and they have been accordingly exposed to systemic risk. As a consequence, many countries, including Argentina (1980-82), Chile (1981-83), Spain (1977-85), Mexico (1995), among others, experienced financial crises, leading to a serious economic recession.

⁴² This is frequently called the central bank's function as the lender of last resort.

attention to it in the practical conduct of policy.

In the aftermath of the GFC, particularly, there was much criticism of central banks' role regarding systemic risks in the financial markets. Macrofinancial imbalances had been accumulated over a long period of time through the linkages between the financial sector and the real economy. These undesirable developments gave rise notably to asset-price bubbles, as a result of which many countries such as the US and the UK began to emphasise the importance of financial stability as a central bank objective. In response to this global trend, the Bank of Korea's role of financial stability has been greatly strengthened in Korea: the current Bank of Korea Act states that the BOK can take more active measures to prevent financial crises and maintain the stability of the financial system (BOK, 2012).⁴³

3.3 Monetary Policy in Korea

Since the end of the 1970s, the monetary policy framework in Korea has undergone many structural changes, the most notable of which was the adoption of inflation targeting at the end of the 1990s. For the twenty years prior to April 1998, Korea maintained a monetary targeting regime. This section briefly reviews the institutional developments supporting monetary policy's shift from a monetary targeting to an inflation targeting regime.⁴⁴

⁴³ The revised Bank of Korea Act of 2011 explicitly specified achieving financial stability as well as price stability as the purposes of its establishment. Consequently, the Bank of Korea was given the right to demand data and materials from non-bank financial institutions while being required to compile biannually a report appraising the soundness of financial institutions in Korea and the macroprudential stability of the financial system as a whole and submit this to the National Assembly.

⁴⁴ Most of this section follows the descriptions in BOK (2008b and 2012).

3.3.1 Brief History: from Monetary Targeting to Inflation Targeting

Korea's "*Financial Stabilisation Programme*" launched only in 1957 sought to create an overall framework for macroeconomic policy, within which monetary policy could be systematically conducted. The main aim of this programme was to curb the high inflation resulting from the dramatically changing social and economic environment and the fiscal laxity that had characterised liberation from Japanese rule, the foundation of the Republic of Korea, the Korean War and post-war reconstruction. The programme provided for a limit on the rate of money growth (M1) to be determined annually or quarterly. Subsequently, in order to handle its chronic balance of payments deficit in its rush for concentrated development, Korea signed a Stand-by Credit Agreement with the IMF in March 1965. Under this Agreement, Korea was required to set a specific target for M1 in consultation with the IMF, which marked an important change in monetary policy operations.

Once the current account started to improve from 1976 onwards, the BOK began to set its own M1 growth target independently of the IMF Agreement. A shift was made to M2 growth as the intermediate target in 1979 because the gap between the actual figures and the desired target had widened. It was at this time that the monetary policy operating framework finally took on the contours of a full-fledged monetary targeting regime.

The money supply target was determined based on the then European Community (EC) method⁴⁵; that is, the BOK set the money supply target, considering a number of expected economic conditions such as economic growth, the rate of inflation, and the

⁴⁵ Since the EC's Council recommended the method's adoption by all of its member countries in 1972, this method has been named the 'EC method'.

change of monetary velocity. Targeting of the M2 growth rate was maintained until the mid-1990s, largely since it remained closer to the target value thanks to the stability of M2 demand.⁴⁶ In Korea, at that time, M2 still maintained a close relationship with prices, while remaining generally its target range. That it did so is largely attributable to relatively late start of financial market and interest rate deregulation, which meant that the financial innovations, which lessened the effectiveness of monetary targeting in the advanced countries, occurred at a relatively slow pace in Korea.⁴⁷

When the trust account system was realigned in 1996, however, M2 demand began to show unstable fluctuations. As a result, in 1997 Korea introduced what was termed a dual monetary targeting system, whereby the rate of increase in MCT (a broader measure of money which is defined as ‘M2+CDs+money-in-trust’) was used as an intermediate target indicator alongside the M2 growth rate.⁴⁸ However, the usefulness of MCT as a monetary target declined with a further financial system reorganisation in 1997 under which reserve requirements were imposed on CDs (certificates of deposit).

In line with the declining effectiveness of monetary indicators, discussions on adopting inflation targeting as an alternative to monetary targeting had begun from the

⁴⁶ Most advanced countries had come to abandon monetary targeting in the 1980s since the rapid financial innovation and liberalisation destabilised the relationship between monetary aggregates and inflation, thus greatly reducing the effectiveness of monetary policy. Therefore, in the early 1990s, central banks in many countries started to take interest in the inflation targeting as an alternative for the operation of monetary policy. See Oh (2000) for a more detailed explanation.

⁴⁷ Financial deregulation spurs financial innovations; innovations take place when the authorities change the operational rules of the financial markets so as to permit activities previously forbidden. This deregulation has been conceived of as “reregulation” since one regulatory code replaces another even though the new regime is more liberal (see, for example, İzgi Koğar (1995) for a discussion of financial innovations and monetary policy). In a similar context, Suzuki (1986) states that financial innovations can be promoted when the financial authorities recognise the obsolescence of the existing statutory framework and deregulate the essential part of it.

⁴⁸ However, the BOK placed more emphasis on MCT than on M2 in the actual conduct of monetary policy. The reason is that when funds move from money-in-trust to time & savings deposits, MCT is not influenced even if M2 expands, therefore counteracting the effects arising from flow of funds between financial assets.

the mid-1990s. Under the revised Bank of Korea Act which came into effect in April 1998, an inflation targeting system (IT) was officially introduced. The BOK started to announce explicitly an annual target rate of inflation determined in consultation with the Korean government. The revision of the BOK Act and the introduction of an IT regime effectively gave the BOK independence in terms of monetary policy operation: the MPC of the BOK now decided the direction of monthly monetary policy and conducted monetary policy in line with this direction. Moreover, the BOK independently formulates and promulgates an operation plan for monetary policy. In that sense, goal independence was to some extent established as well although the inflation target itself is set in consultation with the government (Fischer, 1995).⁴⁹

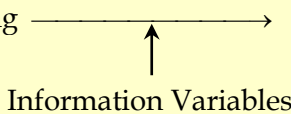
In fact, however, it followed the method of monetary targeting recommended by the IMF as a part of the conditionality on its provision of credit. In other words, a supply ceiling for reserve money was set as an indicative limit corresponding to the appropriate rate of growth in broad-money, M3. Nevertheless, the BOK continued to announce an average growth rate for M3 as an operational target alongside the inflation target in a system similar to the two-pillar system of the European Central Bank (ECB). Notably, from 1999, it was no longer necessary for the monetary authorities to consult with the IMF regarding the appropriate target level of M3 growth, but even so the two-pillar system was retained with the BOK continuing to set an M3 growth target.⁵⁰

⁴⁹ On the legal side, the new Act established the neutrality and autonomy over the conduct of monetary policy: the Governor of the Bank of Korea took over the Chairmanship of the Monetary Policy Committee (MPC) in place of the Minister of Finance and Economy. In addition, in order to reduce government influence on monetary policy, only two among six MPC members are recommended by the government. Hence, the legal independence of the central bank has become better secured than ever before (Oh, 2000).

⁵⁰ There were three reasons; firstly, there were some worries that financial markets could have been disrupted if the monetary targeting implemented over the past three decades were to be abolished suddenly. Secondly, the

Meanwhile, for the two years starting from 2001, the target M3 growth rate was no longer set as an intermediate target but only as a monitoring indicator.⁵¹ This change led to the complete transition to a *pure* IT from the two-pillar system (BOK, 2008b; Roger and Stone, 2005; and Kim and Park, 2006). In 2003, even the monitoring of M3 growth was finally abandoned.

Table 3.1: Monetary Targeting and Inflation Targeting

Type of Targeting	Operating System			
• Monetary Targeting	Policy Instruments	→ Operating Targets	→ Intermediate Targets	→ Policy Goals or Objectives
• Inflation Targeting	Policy Instruments	→ Operating Targets		Policy Goals or Objectives

3.3.2 Current Framework

3.3.2.1 Operating System: Inflation Targeting

The current monetary policy operating framework in Korea is inflation targeting (IT). The central bank announces an explicit inflation target and makes use of its policy instruments to achieve the target. The IT regime has several essential features: (i) an official quantitative target (or target range) for the inflation rate is generally set over one or more time horizons; (ii) the future path of the inflation rate is forecast by using a wide range of information variables such as interest rates, exchange rates and monetary

announcement of an appropriate growth rate for M3 was judged helpful to lower inflation which was still affected by monetary indicators. Lastly, it was intended that both systems should be used during the period of transition until inflation targeting took root.

⁵¹ This means that even if the rate of growth of M3 did not stay within the target range, measures were not taken immediately as they had been when it formed the intermediate target.

aggregates, and (iii) a short-term interest rate⁵² is usually used as a policy instrument (*i.e.*, an operating target) without an explicit intermediate target in order to attain the inflation target taking into account the inflation forecast (Oh, 1999). Among the three features, the inflation target is the essence of the monetary policy framework, in that it not only provides discipline for monetary policy decision-making, but it also serves as an anchor for the formation of public inflation expectations that have a bit great impact on pricing decisions in wages, goods and services.

The IT regime of the BOK can be explained in more detail by breaking down the system into its three main components: the target indicator; the target level; and the horizon.

Target Indicator

During the initial years of 1998–1999 when IT was first implemented in Korea, the BOK’s target indicator was total CPI inflation (or as it is often called ‘headline CPI inflation’). This was mainly because CPI inflation was thought most appropriate as the key anchor for the operation of monetary policy since it represents the indicator of inflation familiar to the public (Oh, 2000).⁵³

⁵² Regarding the implementation of the inflation targeting, some literature, for example, McCallum (1988 and 2000) proposes using the money growth as a policy instrument to conduct monetary policy, rather than interest rates. As in the Taylor rule where a policy instrument is interest rates, in the McCallum’s reaction function that is called the McCallum rule, the policy objective is also an inflation target. The McCallum rule is of the following form:

$$m_t = x^* - v_t + 0.5(x^* - x_{t-1})$$

where m_t is the growth rate of the monetary base, x^* is the target growth rate of nominal GDP, v_t is the growth rate of base velocity, x_{t-1} is the growth rate of nominal GDP. The target value x^* is specified as $\pi^* + y^*$, where y^* is the long-run average growth rate of real GDP. For the Taylor rule in detail, see footnote 68 in Subsection 3.4.3 of Chapter 3.

⁵³ It was additionally considered that the Korean government had already announced CPI inflation forecasts in accordance with the IMF conditionality, so if another indicator were to be used, it could result in public confusion.

In 2000, the target indicator was changed to core CPI inflation (or underlying inflation), which strips out the effect of shocks attributable to a rise in prices of non-grain agricultural and petroleum products.⁵⁴ Core inflation, however, has some weak-points; above all, it does not reflect the day-to-day experiences of the general public because it excludes the prices of agricultural products and petroleum-based fuels that constitute major items in the cost of living. Moreover, the Korean government had long been using the CPI as its inflation indicator in macroeconomic management. In this situation, the BOK's use of core inflation threatened to lead to considerable confusion in public judgment of price levels. Most countries that have adopted IT employ CPI inflation as their target indicator. Taking all these points into consideration, the BOK changed its target indicator back to CPI inflation in 2007.

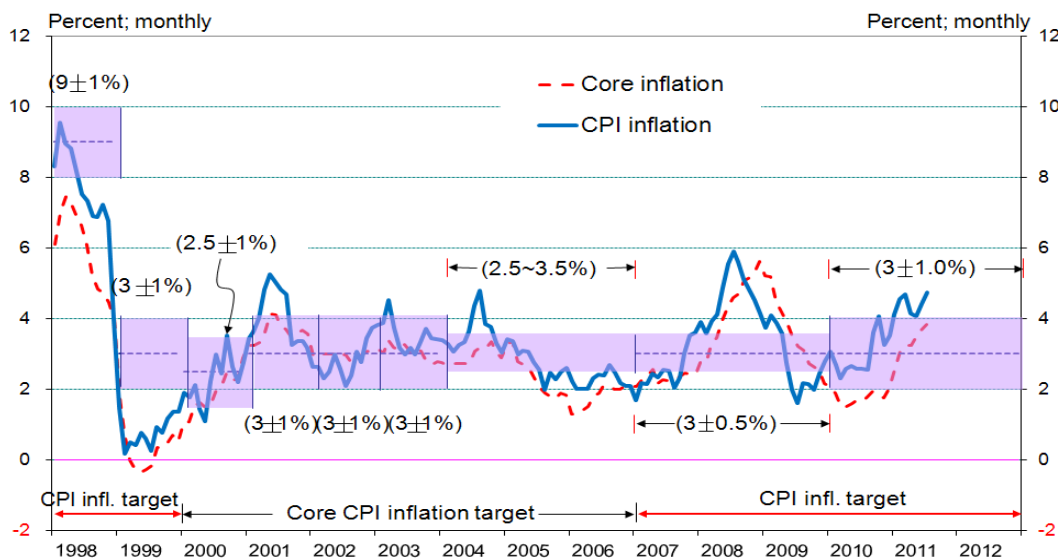
Target Level and Horizon

The BOK sets the inflation target in consultation with the Korean government. The target inflation level is determined in overall consideration of domestic and overseas economic as well as financial market conditions, as in most countries that adopt the IT system. Figure 3.1 shows actual inflation performance and the inflation targets for the period from 1998 to 2012. The target was set on an annual basis from 1998 until 2003.

In 1998, the initial year of the IT system, the target was set at 9 ± 1 percent. Subsequently, it was lowered to 3 ± 1 percent in 1999 and to 2.5 ± 1 percent in 2000, but it was raised to 3 ± 1 percent for the three years from 2001 to 2003.

⁵⁴ Non-grain agricultural product prices are heavily dependent on weather conditions and harvests, and petroleum product prices are greatly affected by changes in international oil prices.

Figure 3.1: Actual Inflation and Inflation Targets



Notes: 1) Consumer prices and core inflation are compared with the same month of the previous year.
2) Shaded areas represent the inflation target range.

Source: The Bank of Korea. February 2012.

In 2004, however, a shift was made to an official medium-term (three year) IT system⁵⁵ upon the following considerations: firstly to allow enough of a time-lag for monetary policy to be transmitted to the economy; secondly, in view of the considerable uncertainties surrounding economic forecasts and the effects of policy actions; and finally, to provide sufficient flexibility for monetary policy to tolerate temporary or one off short-run economic fluctuations, for example, allowing temporary deviations of inflation from the target. Thus, for the first medium-term period of 2004–2006, the inflation target was set at a range of 2.5~3.5 percent (annual average basis during the period). In 2007, the target was set at 3.0 percent for the second medium-term of 2007–

⁵⁵ Clause 1 of Article 6 of the Bank of Korea Act (entry into force, 1 April 1998) required the Bank of Korea to establish an inflation target ‘every year’, but under the revised Act of 2003 (entry into force, 1 January 2004) the word ‘every year’ was removed and the BOK was able to set an inflation target from a medium-term perspective..

2009. In the current system, the application period (three year) and method of evaluation (annual average rate of inflation during the period) are substantially the same as with the first medium-term inflation target. The difference is that the target indicator was changed from the core CPI measure to headline CPI, and the method of establishing the target altered from a target range to a midpoint with a tolerance band of ± 0.5 percentage point (BOK, 2004 and 2007). Meanwhile, in 2010, the inflation target was set at 3.0 percent for the third medium-term of 2010–2012, with a tolerance range of ± 1.0 percentage point around this target, in terms of the 12-month rate of change in the consumer price index.

3.3.2.2 Method of Operation

The Official Policy Rate

Under the monetary targeting regime in force up until 1997, monetary policy was implemented by using an intermediate monetary growth target and employing reserve money as an operating target to attain it. This formulation was premised upon the assumption of a stable relationship between reserve money and money supply. Monetary policy was operated by converting the monetary target into reserve money and achieving the required scale of reserve money through open market operations.

However, the monetary aggregate indicator showed unstable movements due to realignment and financial innovation, and hence its relationship with the ultimate goals of monetary policy was largely blurred. This resulted in a decline in the effectiveness of monetary policy indicators. As a consequence, any chosen monetary aggregate was found to gradually lose its effectiveness as an intermediate target. And the introduction of

an IT system following the 1997–1998 Korean currency crisis drove a shift to an interest rate-oriented monetary policy in Korea.

From May 1999 onwards, the overnight call rate, which is the equivalent of the US Federal Funds rate, started to be used as the operating target for the conduct of monetary policy. The level of the call rate was decided at the monthly meeting of the Monetary Policy Committee (MPC). The introduction of the call rate target framework contributed substantially to widening flexibility in adjusting liquidity, which helped dampen market unrest in that it allowed a shift reaction through the expansion of liquidity supply by way of open market operations in periods of financial tension such as the Daewoo business group's collapse (in September 1999) and the credit card debacle (during the period of 2000–2003). The call rate, though, tended to become closely tied to its target level regardless of liquidity conditions in the money market, which greatly weakened its signalling of information about the market and its liquidity-allocation function. This constraint on the volatility of the call rate led to short-term transactions of funds becoming excessively concentrated in the call market, hindering the development of the money market. This acted to impede the seamless operation of the interest-rate transmission channel of monetary policy.

Under these circumstances, there was a need to boost the effectiveness of an interest rate-oriented monetary policy and create conditions for the development of short-term money markets as well. To this end, the BOK in March 2008 changed the policy rate from the 'call rate target' to the 'Bank of Korea Base Rate,' which is the standard rate applied in transactions such as repurchase agreements (RPs) between the Bank of Korea and its counterpart financial institutions (BOK, 2008a,b).

The Policy Rate Decision and Communications

The Monetary Policy Committee (MPC) of the BOK makes decisions about the policy interest rate, *i.e.*, the Bank of Korea Base Rate. The MPC basically meets twelve times each year on the first Thursday of the month.

In order to assess economic conditions including inflationary pressures, like most other central banks, the Committee uses an inflation forecast and other relevant indicators. This is dubbed the ‘Look-at-Everything Approach’ which monitors as wide a range of information variables as possible. Such variables include production, demand, real asset prices, the P^* ratio⁵⁶, the output gap, the NAIRU (non-accelerating inflation rate of unemployment) and so on (Kim and Park, 2006; Sánchez, 2009).

Together with price stability, which is stipulated as the primary objective of monetary policy in the Bank of Korea Act, both the reduction of short-term economic fluctuations and the stability of financial markets are important policy goals as well. In this regard, “flexible” inflation targeting rather than “strict” inflation targeting and an ‘eclectic’ approach⁵⁷ characterise Korea’s monetary policy. In addition, as with what are termed ‘Greenspan’s baby steps,’ the target policy rate is adjusted gradually (by 25~50 bps), and when it has been determined, open market operations are carried out to move the actual policy rate close to the policy rate target.

Communication is now regarded as an important monetary policy tool which may

⁵⁶ The P^* ratio is defined as the ratio of the long-run equilibrium price level to the current price level.

⁵⁷ When inflation rate appears to move above the target range amid an economic slowdown or financial instability, the central bank will face difficulties in choosing the appropriate policy direction. In these situations, the central bank should focus on the objectives that it judges most urgent under prevailing situations, as long as this does not detract greatly from price stability. In this flexible or eclectic approach, the central bank’s judgment on the economic situations plays an important role in determining the policy direction (Kim, 2006).

affect financial stability and the real economy through its impact on agents' expectations. Hence, the BOK announces the direction of monetary policy as soon as a decision is made, informing the public about current monetary policy issues and future policy directions. Twice a year (in March and September of each year), the BOK submits a Monetary Policy Report to the National Assembly, showing whether the inflation target has been achieved and describing the monetary policy actions taken and the future policy directions. The Governor of the BOK attends the Finance and Economy Committee of the National Assembly to testify concerning the operating stance of monetary policy and the economic outlook (see BOK (2008b) for a more detailed explanation).

3.3.3 Identifying Monetary Policy Shocks and Uncertainties in Korea

In recent years, uncertainty has been the focus of great attention in drawing up and conducting monetary policy in Korea as elsewhere. This was attributable several changes in the economic situation; firstly, from the 1990s, many industrial countries entered a phase of low and comparatively stable inflation. Improved monetary policy management as well as the greater openness of economies and closer integration of the world economy (*i.e.*, globalisation) were seen to have contributed to this development (IMF, 1999). A leading concern for monetary policy came to be no longer how to achieve low inflation but how best to conduct monetary policy in an environment of low and stable inflation. This prompted central banks to concern themselves greatly with handling uncertainty; secondly, the much closer international linkages owing to the liberalisation and globalisation of the real economy and financial markets added to the potential sources of shocks that were unpredictable and difficult to quantify. At the same time, there have

been large advances in econometric tools which have enhanced computational capacity; for instance, the possibility of undertaking stochastic simulations has allowed central bank economists to develop a more systematic analysis of uncertainty and strategies for contending with it.

The sources of shocks or uncertainty associated with the conduct of monetary policy in Korea can be domestic or international in origin. Some sources of shocks can be events that are certain to occur, but whose exact outcomes are often difficult to know. Domestic examples are the financial market unrest centring around the Daewoo Group in 1999, a sharp expansion of household credits in 2002, the North Korean nuclear issue, etc. Together with these, over the last decade, global scopes of uncertainty have become more pervasive. These examples entering the set of uncertainties faced by policymakers are events such as the 1997–1998 Korean currency crisis and Russian debt default, the large run-up in world commodity prices, the 11 September 2001 incident in the US, the turmoil of 2007–2009 in the US sub-prime mortgage market, and Lehman brothers' collapse in September 2008.

In addition, the persistence of shocks is unknowable. Given that the Korean economy is highly vulnerable to external shocks or uncertainties, this subsection investigates examples of uncertainties that the central bank has confronted in the course of actual conduct of monetary policy.

● **1997–1998, Korean Currency Crisis and Credit Crunch in the Banking Sector**

The exchange rate of the Korean won to the US dollar peaked at 1,965 on 24 December 1997, and maintained a level of 1,600~1,700 won per dollar during early 1998.

The BOK, acting under its agreement with the IMF, raised the interest rate applied in its open market operations to as much as 35 percent to stabilise the exchange rate. As major market interest rates consequently rose to the level of 30~40 percent, Korea experienced a period of unprecedentedly high interest rates.

During the course of the contraction of business activity after the currency crisis, a credit crunch erupted as banks cut back their lending.

- **1999, Financial Market Unrest Centred around the Daewoo Group**

Following severe problems among member companies of the Daewoo Group, a restructuring plan was unveiled on 19 July 1999 and guidelines were established for the workout programs of 12 Daewoo affiliates during August. This led to severe financial market turmoil. In particular, once it became generally known that a considerable volume of the corporate bonds issued on a large-scale by the Daewoo Group following the currency crisis had been acquired by investment trust companies' funds in the form of bond-type beneficiary certificates, fears arose that the investment trust companies would be hit by knock-on insolvencies.

- **2000, Inflationary Pressures and Capital Market Crunch**

From June 2000 onwards, prices deviated from their previous stable track, and rose steeply. CPI inflation showed a steep upward trend, registering 0.5 percent compared to the previous month (comparisons are the same below) in June, 0.3 percent in July, 0.8 percent in August, and then increasing to 1.5 percent in September. Additionally, the release of second-quarter GDP growth of 9.6 percent caused fears that with the widening of the positive output gap taking the slack out of the economy excess demand pressures

would progressively built up.

From May 2000 onwards, financial markets were again thrown into turmoil by the liquidity crises of Saehan Group and Hyundai Engineering & Construction Co. In the latter half of 2000, there was a bunching of the maturities of corporate bonds that had been issued in 1997. With banks averse to granting credit following the liquidity problems of large companies, there was a strong possibility that large-scale insolvencies might arise as enterprises with low credit standing could well face difficulties in rolling over their corporate bonds.

- **2001, Global Recession and Uncertainties caused by Geopolitical Risks**

From the beginning of the latter half of 2001, US economic growth remained virtually stagnant. As a result, the possibility of a global recession increased. To add to this, the effect of the events of September 11, the subsequent outbreak of war against Afghanistan and fears aroused by a perceived threat of biochemical terror further depressed economic activity. In order to avert financial turmoil and provide the impetus for a recovery of economic activity, the US Federal Reserve continued to lower interest rates, and other major central banks around the world joined it in greatly lowering interest rates.

- **2002, Expansion of Household Credits amid Mounting Uncertainty of the External Environment**

In a low interest-rate environment, household loans grew explosively by 45.0 trillion won in 2001 and 61.6 trillion won in 2002. Due to the rapid expansion of household loans and a subsequent sharp rise in house prices, there were worries that asset

markets might become overheated or inflationary expectations among the general public might become embedded in the economy. As a result, the question as to how monetary policy should react to changes in asset prices emerged as a contentious issue in Korea as it had in major countries.

From early in the second half of 2002, external uncertainty greatly increased due to geopolitical factors, including the North Korean nuclear issue and the looming threat of the outbreak of a US war against Iraq. At the same time as a sharp run-up in world oil prices, major US firms, notably, Enron and WorldCom, faced the risk of bankruptcy. Consequently, stock prices declined sharply in all the major countries. Korean stock prices also fell and the confidence of economic agents shrank so that the downside risks to growth increased greatly.

● 2003, Heightened Financial Market Instability and Geopolitical Risks

The BOK confronted a number of uncertainties in the course of maintaining its monetary policy stance. Above all, house prices followed an upward track from February 2003 onwards⁵⁸, bringing greater uncertainty to the policy environment. Despite the sluggishness of economic activity, house prices were rising sharply, sparking a debate over how monetary policy should deal with this.⁵⁹

And, uncertainty was running high owing to the increased possibility of financial

⁵⁸ The prices of apartments in the Seoul area exhibited a steep upward trend with a 5.4 percent rise in the second quarter of 2003 and rose by 4.4 percent in the third quarter.

⁵⁹ The issues of contention were that the Bank should not lower its policy rate, or rather, should raise it to cope with house price-bubbles. The Bank judged that countering sharp increases in house prices through interest rate policy would face certain limitations. It was true that prolonged low interest rate policy had contributed in part to the rise in real estate prices, but there were other factors including the imbalances between housing supply and demand in certain districts that reflected disparities in schooling and quality-of-life, and the speculative demand for apartments slated for reconstruction.

market instability and continuing geopolitical risks including the outbreak of the US-led war against Iraq (March 2003) and the North Korean nuclear issue. In addition, there were worries over a deep contraction of economic activity under the negative impact of the spread of the SARS epidemic, decreases in private consumption due to households' heavy debt burden, and the delay in the global economic recovery.

- **2004, Sharp Rise in Oil Prices and the Weakening of Global IT Business**

Investment and consumer confidence among economic agents, which had shrunk abruptly from May 2004 onwards because of the uncertainties at home and abroad, weakened further under the impact of the sharp run-up in international oil prices in early July 2004. It was also expected that the pace of growth of the world economy would slow in response to the rise in oil prices and the Federal Reserve's shift to a tighter monetary policy. Meanwhile, owing to the possibility of global IT business reversing to a downward trend, it was feared that the expansion of exports, which had been the mainstay of economic growth for some time, would falter.

- **2005, Rapid Rise in Real Estate Prices and Oil Prices**

Keeping interest rates low for a considerable length of time to support the recovery of economic activity led to a number of malign side-effects such as increasing upward pressure on asset prices caused by financial speculation. House prices, which had been stabilised with the introduction of a package of real estate measures on 29 October, 2003, started to surge from the beginning of 2005. In addition, there were concerns that the trend of high oil prices might continue longer than expected as oil prices defied forecasts by remaining on a steeply rising course.

- **2006, Heightening Geopolitical Risks and Slowdown in Economic Activity**

Amid heightening geopolitical risks, including the Iranian nuclear issue and attacks on Nigerian oil facilities, international oil prices rose steeply from the beginning of 2006. Moreover, from July 2006 onwards, a number of events taking place both at home and abroad acted as sources of risk factors. Geopolitical risk increased greatly with the eruption of armed conflicts in the Middle-East and international oil prices rose steeply again. For Korea, in particular, various events also occurred including North Korea's test-firing of missiles and strikes at several large firms. All of these combined to slow down economic activity for a while and reduced economic agents' confidence.

- **2007, Sharp Increase in Oil Prices and Financial Market Unrest**

Growing macroeconomic uncertainty was typified by sharply rising international oil prices and heightened international financial market-unrest arising from the US sub-prime mortgage meltdown. Notably, from late July 2007, the volatility of price variables such as market interest rates and share prices increased markedly in the financial markets of the US and many countries around the world including Korea under the impact of concerns over a credit squeeze triggered by the turmoil in the US sub-prime mortgage market.

- **2008–2009, Rapid Increase of Uncertainty Resulting from Global Financial Crisis and Economic Recession**

Lehman Brothers' filing for bankruptcy protection in September 2008 led to the deterioration of the international environment in the forms of global financial market turmoil and economic recession. Interest rates, share prices and exchange rates became

increasingly volatile and a credit crunch emerged. The BOK's monetary policy focus was to minimise the negative effects on the financial markets and the real economy caused by these economic conditions. It cut its Base Rate from 5.25 percent in October 2008 to a record-low of 2.0 percent in February 2009, resulting in a total cut of 325 bps in five months. The BOK then expanded the supply of Korean won and foreign currency liquidity. Due to this accommodative monetary policy, the Korean real economy showed a gradual improvement while stock prices rebounded and the Korean won/US dollar exchange rate demonstrated downward stability. Despite these continued improvements in the financial and economic situation, there remained a high degree of uncertainty in the economic environment at home and abroad.

- **2010–2011, Increasing Uncertainty Arising from Global Financial Crisis and Economic Recession**

Despite the steady improvement of domestic real economic activity, the demand-side pressures on prices were not very great, and the Korean won/US dollar showed downward stability, easing below its level of the previous year. Subsequently, CPI inflation remained subdued. The BOK kept its key interest rate at a historic low of 2.0 percent in view of the high degree of uncertainty about the future economic outlook arising from the weak economic recovery in major advanced countries and the possible reemergence of global financial market turmoil.

From the latter half of 2010, however, the economy continued its upward trend, in consequence of which upward pressures on prices appeared gradually. The Bank of Korea shifted its policy stance toward gradually lessening the degree of monetary accommodativeness, normalising interest rates: it adjusted the Base Rate upward in five

steps, raising it by 25 bps from July to June 2011. As a result, the Base Rate rose from 2.0 percent to 3.25 percent.

During the latter half of 2011, the BOK maintained the Base Rate at 3.25 percent since the downside risks to growth and uncertainty in domestic and overseas financial markets had increased owing to the sovereign debt problems in the eurozone, the economic slowdown in major countries and the global financial market unrest.

3.4 Policy Interest Rate Movements: Evidence in Korea

3.4.1 Stylised Facts

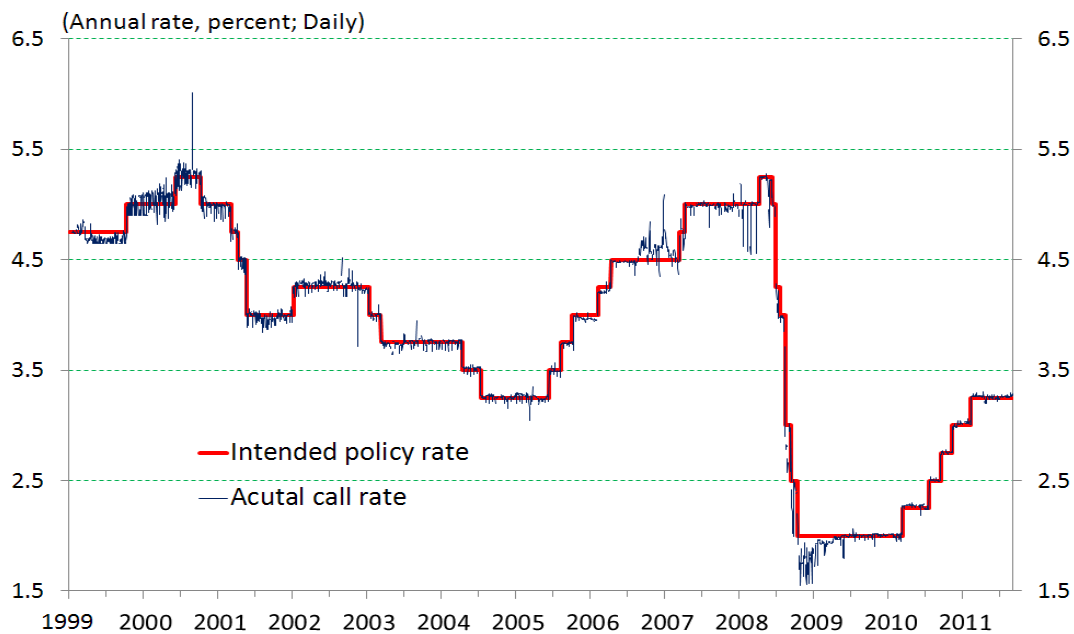
Figure 3.2 plots the path of the intended policy rate from May 1999 through December 2011, and Table 3.2 provides statistics on the frequency and the magnitude of changes in policy rates in Korea. Overall, the path of the short-term policy interest rate that results from the conduct of monetary policy tends to remain unchanged for some time in the face of a changing environment. More specifically, the pattern of policy rate movements can be described by several characteristics.

3.4.1.1 Infrequent Changes in Policy Interest Rates

Changes in policy rates by the central bank are relatively rare given the frequency with which new information about the state of the economy is released. Almost every day the economic space and financial markets are filled with a multitude of new items of information. In general, however, this should not lead to large day-to-day revisions in the central bank's forecasts on inflation and output. It may be, of course, true that whether or not revisions in forecasts are needed hinges on the size of the shocks or the importance of

information contained in the news. Despite this, adjustments of policy rates are quite infrequent. Some would argue that the policy rate should be changed in accordance with the arrival of new important information, if policy were to react in order to cope with shifts in asset prices. This would imply that more frequent changes in policy rates should be made than is the conventional practices. In practice, the BOK moves interest rates less frequently than once a quarter, and sometimes goes several quarters without any change in rates.

Figure 3.2: The Path of the Intended Policy Rate Target in Korea, May 1999–December 2011



Note: The policy rate was changed from the 'call rate target' to 'the Bank of Korea Base Rate' from March 2008 onwards.

In Korea, over the last decade or so, there have been 30 changes in policy rates. Since May 1999, the Bank of Korea has adjusted, on average, its policy rate once every

154 days (about $5\frac{3}{25}$ months), with about 17 months⁶⁰ being the longest period without a change.

Table 3.2: Policy Interest Rate Adjustments in Korea, May 1999–December 2011

Number of changes		Average duration (in days)		Absolute size of changes (in average basis points)			
Continuations	Reversals	All Continuations	Reversals	All Continuations	Reversals		
24	6	154	125	273	32	33	25
(+ +: 13, --:11)	(+ -: 3, -+: 3)	(+ +: 161, --: 82)	(+ -: 187, -+: 359)	(+ +: 25, --: 43)	(+ -: 25, -+: 25)		

Notes: + + means two more successive increases in policy interest rates (policy tightness)
+ – means increase followed by decrease in policy interest rates
– + means decrease followed by increase in policy interest rates
– – means two more successive decreases in policy interest rates (policy easing)

3.4.1.2 Successive Changes in the Same Direction

Changes in policy rates by the central bank are often carried out in the form of multiple steps within a single policy rate movement. These changes appear to be frequently followed by relatively small and additional changes in the same direction. For the sample period, 80 percent of the policy rate alterations showed continuations in the direction of previous policy changes: the number of consecutive increases (monetary policy tightnesses) in policy rate is 13 times and that of consecutive decreases (monetary easing) 11 times. These continuations often occur in rapid succession with an average of 125 days in contrast to reversals with an average of 273 days. Moreover, the number of reversals, which means a change of policy stance, is just 6 times among a total of 30 times changes. The central bank appears to have a strong reluctance to frequently change

⁶⁰ The policy rate remained unchanged at 2.0 percent from 12 February 2009 to 8 July 2010.

the direction of interest rates.

As is evident in Figure 3.2, it is common for three or four moves to be made in the same direction before a move is made in the opposite direction, which implies the existence of autocorrelation in policy interest rates. This can be confirmed in the autocorrelation coefficients, calculated by using the level of policy interest rates. As is reported in Table 3.3, quarterly policy rates show positive autocorrelations. These autocorrelations up to the second quarter are strongly significant.

This fact suggests that like most other central banks, the BOK deliberately chooses gradual adjustment paths for the short-term interest rate for the sample period.⁶¹

Table 3.3: Autocorrelations of the Policy Interest Rate, 1999:q2–2011:q4

	Lags in quarters					
	1	2	3	4	8	10
Policy base rate	0.923**	0.781*	0.626*	0.463	-0.106	-0.276
Actual call rate	0.921**	0.778*	0.627*	0.470	-0.101	-0.262

Note: The asterisks (**) and *) represent significantly different from zero at the 5 percent and the 10 percent levels, respectively.

3.4.1.3 Asymmetric Adjustments of Interest Rates

There might be a possibility of asymmetric adjustment of policy interest rates in Korea. This pattern can be discussed from two perspectives. One is that the average size of interest rate change at turning-points is found to be just 25 basis points (hereafter, referred to as ‘bp’), which is much smaller than it is for continuations, 33 bp. This

⁶¹ Similar patterns are observed in many other countries. See, for example Debelle and Cagliarini (2000); Lowe and Ellis (1997) for evidence from other countries.

evidence might partly reflect the fact that because the central bank is not confident of the correct state of the economy in periods when the real economy is in an upturn or downturn, it must be much more cautious in reversing its interest rate policy.

The other is that the average size of changes for the period of consecutive decreases, 43 bp, is relatively greater than it is for the period of consecutive increases, 25 bp. In other words, the policy rates in Korea is adjusted differently under expansionary *versus* contractionary monetary policy, meaning that the BOK behaves more cautiously in raising interest rates than lowering them. More specifically, over the past decade, there have been 13 instances of successive increases and 11 of successive decreases: amongst the successive decreases, there were 3 of 50-bp decreases (19 September 2001, 9 January 2009 and 12 February 2009); 1 of a 75-bp decrease (27 October 2008), and 1 of an 100-bp decrease (11 December 2008).

3.4.1.4 Long Pause before Reversals in Policy Interest Rates

Reversals in the direction of policy interest rates are generally preceded by a relatively long period without a change in the policy rate. As explained earlier, the average time between interest-rate changes is greater in the case of reversals with an average of 273 days than it is for continuations with 125 days. This means that the BOK kept policy interest rates unchanged for about nine months before reversing its preceding policy stance.

3.4.2 Comparison with Selected Advanced Countries

As seen in Table 3.4, the four characteristics that we discussed above can be also found

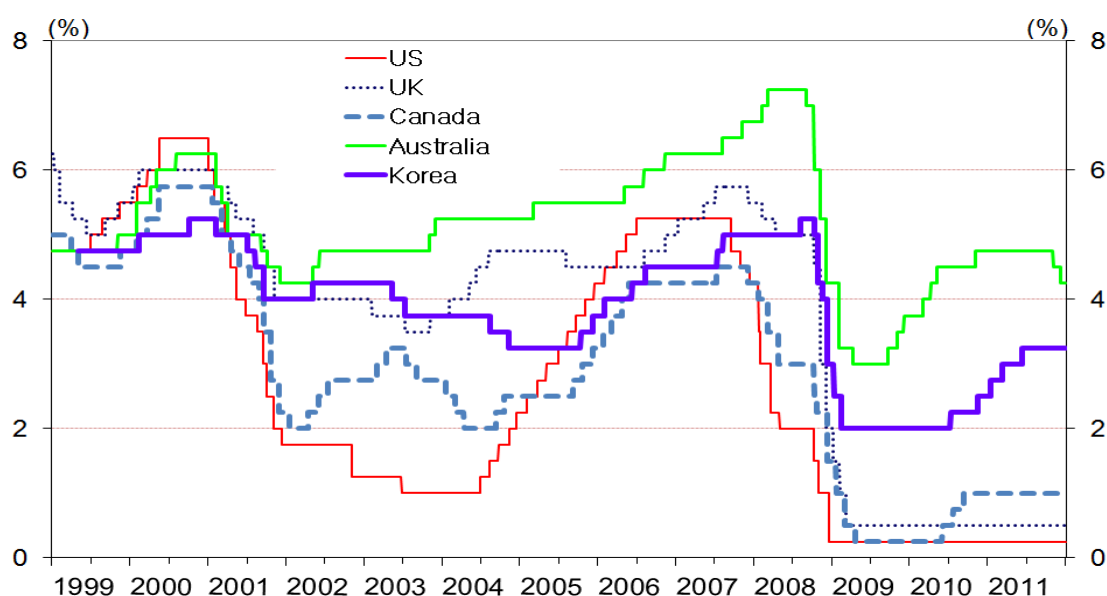
in movements in policy interest rates in major advanced countries: specifically the US, the UK, Canada and Australia.

Table 3.4: Policy Rate Adjustments, January 1999–December 2011

	Number of changes		Average duration (in days)		Absolute size of changes (in average basis points)		
	Continuations	Reversals	All Continuations	Reversals	All Continuations	Reversals	
US	42 (++: 21, --: 21)	4 (+-: 2, -+: 2)	79	57 (++: 50, --: 65)	308 (+-: 339, -+: 276)	36 (++: 26, --: 45)	38 (+-: 50, -+: 25)
UK	31 (++: 11, --: 20)	6 (+-: 3, -+: 3)	100	73 (++: 69, --: 75)	243 (+-: 294, -+: 191)	34 (++: 25, --: 43)	25 (+-: 25, -+: 25)
Canada	42 (++: 18, --: 24)	7 (+-: 3, -+: 4)	87	78 (++: 91, --: 69)	139 (+-: 163, -+: 121)	32 (++: 26, --: 38)	25 (+-: 25, -+: 25)
Australia	32 (++: 21, --: 11)	6 (+-: 3, -+: 3)	124	115 (++: 151, --: 47)	172 (+-: 135, -+: 209)	35 (++: 26, --: 55)	30 (+-: 38, -+: 25)

Notes: ++ means two more successive increases (tightnesses); +- means increase followed by decrease; -+ means decrease followed by increase; -- means two more Successive Decreases (easing).

Figure 3.3: Policy Interest Rates, May 1999–December 2011



3.4.3 Interest-rate Smoothing in Korea

The four stylised patterns in the policy interest rate path described in the previous section are also found in other countries (see, for example, Goodhart (1999a); Debelle and Cagliarini (2000); and Lowe and Ellis (1997) for evidence in other countries). Such policy rate patterns characterise the central bank's reaction to inflation and the output gap as being less aggressive than the optimising central bank behavior would predict.

The tendency of central banks to adjust their policy instruments in a slow and moderate manner is dubbed “interest-rate smoothing⁶²”, which is used interchangeably with ‘partial adjustment’, ‘gradualism’ or ‘inertia’. Sack and Wieland (2000) define interest-rate smoothing as a high degree of partial adjustment and limited overall responsiveness of the interest rates. They argue that deviations of inflation from its target or output from its potential will lead to a sequence of policy adjustments in the same direction until they have been restored to their desired path (partial adjustment of interest rates to changes in inflation or/and output), and the overall responsiveness of the interest rate rule is determined by the sizes of response coefficients of inflation and output in the interest rate reaction functions⁶³.

3.4.3.1 Two Approaches to Analysing the Interest-rate Smoothing Behavior and their Implications

There are two approaches to explaining and analysing the interest-rate smoothing

⁶² More detailed empirical evidence on the existence of interest-rate smoothing was first provided by Rudebusch (1995) for US data.

⁶³ Smaller regression coefficients on inflation and output imply more timidity in the responsiveness of the interest rate, causing lower interest-rate fluctuations.

behaviour of central banks. One approach commonly employed in many empirical analyses of monetary policy incorporates an explicit incentive for interest-rate smoothing in the central bank's objective function (see, for example, Rudebusch and Svensson (1999a and 2002), Collins and Siklos (2004), and Castelnuovo and Surico (2004), among others). This literature justifies the partial adjustment mechanism by including an interest-rate change term in the central bank's loss function. The authors argue that central banks are reluctant to change their policy interest rates boldly, attempting instead to operate them less aggressively towards the desired target levels. In fact, it is well known that this gradualist pattern of policy interest rate movements boils down to providing evidence that central banks may have a separate objective which is to minimise changes in interest rates along with the task of managing dual goals of price stability and sustainable economic growth.

As for the other approach, there exists an extensive literature on estimating interest rate rules which include a past interest rate term, in addition to the variables associated with policy goals such as inflation and output stabilisation without any consideration of loss function having an interest-rate change term. This approach has been employed by numerous researchers, for example, Clarida *et al.* (1999 and 2000), Rudebusch (2001 and 2002b), and Orphanides (2001 and 2002), among others. This approach reflects the point that because the monetary policy authority systematically reacts to macroeconomic variables such as inflation and the output gap, these gradual patterns in interest-rate movements are affected by the persistence in the movements of those variables.

However, we can show that the first approach implies the second one. In other words, the first approach is a theoretical method of justifying the empirical results from

policy rules with smoothing. Suppose that the structural models are given by:

$$\pi_t = \alpha E_t \pi_{t+1} + \beta y_t + \varepsilon_t^s, \quad \alpha \in [0,1], \beta \geq 0 \quad (3.1)$$

$$y_t = \phi E_t y_{t+1} + \psi (i_t - E_t \pi_{t+1} - \bar{r}) + \eta_t^d, \quad \phi > 0, \psi < 0 \quad (3.2)$$

Equation (3.1) is the standard New-Keynesian Phillips curve in which a measure of inflation, π_t , depends on expected future inflation, $E_t \pi_{t+1}$, the output gap, y_t , and a cost-push shock, ε_t^s ⁶⁴. The parameter α governs the degree to which the current period's inflation rate is influenced by the next-period expectations of inflation at the current time and the parameter, β , governs the slope of the curve. Equation (3.2) is the IS equation in which the output gap, y_t , depends on the expected future output gap, $E_t y_{t+1}$, the real interest rate gap, defined as $i_t - E_t \pi_{t+1} - \bar{r}$, where i_t denotes the one-period nominal interest rate which is under the control of the central bank and \bar{r} is the desired real interest rate (or the long-term equilibrium real interest rate), and on a demand shock, η_t^d ⁶⁵. The parameter, ϕ , governs the sensitivity of the current period's output gap to the expected future output gap. The parameter, ψ , governs the sensitivity of the current period's output gap to real interest rate. Both shocks, ε_t^s and η_t^d , are assumed serially and mutually uncorrelated: $\varepsilon_t^s \sim i.i.d. N(0, \sigma_\varepsilon^2)$ and $\eta_t^d \sim i.i.d. N(0, \sigma_\eta^2)$.

⁶⁴ See Galí (2008, p.48-49) for derivations of this type of relationship.

⁶⁵ Since \bar{r} is a constant, the inclusion of the equilibrium real interest rate in Equation (3.2) does not affect the derivation of the optimal policy rule. Hence, it is often omitted from the IS equation for simplicity of exposition.

Assume that under discretion⁶⁶, central banks set the nominal interest rate, i_t , at the beginning of period t on the basis of expectations formed at time $t-1$. Their optimisation problem is:

$$\min_{\{i\}} E_{t-1} \sum_{k=0}^{\infty} \delta^k L_{t+k}, \quad (3.3)$$

subject to Equations (3.1) and (3.2), where δ is the discount factor, and

$$L_t = \frac{1}{2} [(\pi_t - \pi^T)^2 + \lambda y_t^2 + \sigma(i_t - \bar{i})^2 + \zeta(i_t - i_{t-1})^2] \quad (3.4)$$

is a conventional per-period quadratic loss function, where π^T is the level of inflation (implicitly or explicitly) targeted by the central bank; \bar{i} the equilibrium or desired nominal interest rate, defined as $\bar{i} = \bar{r} + \pi^T$. And in the loss function, λ , σ and ζ are positive parameters that capture the relative weights on the output gap stabilisation, interest rates stabilisation and interest-rate smoothing, respectively.

Assume $k=1$ for simplicity where k determines the degree to which policy is forward-looking. According to the existing literature (*e.g.*, Clarida *et al*, 1999); Walsh, 2010), solving this optimisation problem under discretion, leads to the following first-order conditions with respect to the current interest rate, i_t ⁶⁷:

$$E_{t-1} \left[(\pi_t - \pi^T) \frac{d\pi_t}{dy_t} \frac{dy_t}{di_t} + \lambda y_t \frac{dy_t}{di_t} + \sigma(i_t - \bar{i}) + \zeta(i_t - i_{t-1}) \right] = 0. \quad (3.5)$$

⁶⁶ The debate on whether policymakers should commit to a certain course of action or have the perfect flexibility to attain their policy goals has been a central question in setting monetary policy. In practice, it is often found that no central bank commits itself in the design of monetary policy.

⁶⁷ To simplify the problem, it is assumed that $\delta = 1$.

Using (3.1) and (3.2), the optimal monetary policy rule is obtained as follows:

$$\hat{i}_t = (1 - \rho)[c + \theta(E_{t-1}\pi_t - \pi^T) + \chi E_{t-1}y_t] + \rho i_{t-1}, \quad (3.6)$$

where \hat{i}_t denotes the optimal interest rate, $c = \bar{i}$, $\rho = \frac{\zeta}{\sigma + \zeta}$, $\theta = -\frac{\beta\psi}{\sigma}$, and $\chi = -\frac{\lambda\psi}{\sigma}$. In particular, $\rho \in [0, 1]$ is a parameter that captures the degree of smoothing in the time path of the actual policy interest rate, i_t , and c is a constant interpretable as the nominal policy interest rates in a steady-state. Equation (3.6) is the so-called simple *modified* monetary policy rule⁶⁸ due to the inclusion of the lagged level of policy interest rate term, i_{t-1} , as a third argument.

Under rational expectations, we can replace *expected* inflation and output gap with their respective *actual* values, thereby obtaining the following *empirical* model of policy reaction function with a partial adjustment term, given by:

$$i_t = (1 - \rho)[c + \theta(\pi_t - \pi^T) + \chi y_t] + \rho i_{t-1} + u_t, \quad (3.7)$$

where the last term, u_t , stands for the expectational errors caused by replacing the expected values of variables with actual values of explanatory variables. In Equation (3.7), the

⁶⁸ Taylor (1993) suggests that the US Federal Funds rate within a given period should be set in response to a change in three economic variables: the equilibrium nominal interest rate (\bar{i}), the current deviation of inflation from its target ($\pi_t - \pi^T$), and the current value of the output gap (y_t). This relationship is popularly known under the name of the Taylor rule, which looks as follows:

$$\hat{i}_t = \bar{i} + 1.5(\pi_t - \pi^T) + 0.5y_t, \text{ where } \bar{i} = \bar{r} + \pi^T, \bar{r} : \text{the equilibrium real interest rate.}$$

Since Taylor took the values 2 for \bar{r} and for π^T , respectively, the value \bar{i} is equal to 4 percent. This equation is not based on a regression result, but it remarkably well describes the behaviour of the Fed during the period from 1987 up to 1992 (which is a considerable period of the Greenspan era: 1987-2006). This “rule” states that the Federal Funds rate increases if inflation is above the target rate of 2 percent or if the real output is above the potential output. When inflation equals 2 percent and output equals potential output, the Federal Funds rate will be set equal to 4 percent. As it can be used for the evaluation of current policies and also to determine those of the future, the Taylor rule has been received a lot of attention from academics and policymakers and been much discussed.

parameters, θ and χ , measure the response of the policy interest rate to inflation, π_t and the output gap, y_t , respectively. Ultimately, the empirical version of the policy interest rate is represented as a weighted average of some desired values. In other words, the policy interest rate is dependent on the lagged interest rates and on the state of the economy.

3.4.3.2 Forward-looking Taylor Rules

Following Clarida *et al.* (1998, 1999 and 2000), assume that the central bank has at least some degree of autonomy over its monetary policy. In other words, the domestic monetary policy is not subject to any significant external constraints such as the need to meet exchange rate targets. Given this assumption, the central bank sets a target for the nominal short-term interest rate, i_t^T , based on the current state or future condition of the economy. Then, the target rate in each period is represented by a function of the gaps between expected inflation and output, and their corresponding target levels. Specifically, we have:

$$i_t^T = \bar{i} + \theta(E_t\{\pi_{t+k}|\Omega_t\} - \pi^T) + \chi E_t\{y_{t+l}|\Omega_t\}, \quad (3.8)$$

where i_t^T is the target for the policy interest rates at time t . \bar{i} is the desired nominal interest rates when both inflation and the output gap are at their target levels. π_{t+k} denotes a forecast of inflation rate in period $t+k$ ⁶⁹. y_{t+l} stands for a forecast of the output gap in period $t+l$, defined as the percentage deviations of the actual GDP from its corresponding target. Both forecasts are assumed to be made with all relevant information available at time t by the central bank. π^T is the target or desired level of inflation. E is the

⁶⁹ Therefore, $E_t\{\pi_{t+k}\}$ is the expectation of inflation in period $t+k$, which is formed at time t .

expectation operator, and Ω_t denotes the information set⁷⁰ at the time policy decisions are made⁷¹. Note that the subscripts, k and l , determine the degree to which policy is forward-looking and therefore are referred to as the target feedback horizons.

On the empirical side, numerous earlier studies have emphasised that policy rules like (3.8) provide good descriptions of the way central banks behave. It is true that Taylor (1993) proposes a rule where the policy interest rate responds to *lagged* inflation and the output gap as opposed to their expected future values. The forward-looking rule explained above nests the Taylor rule as a special case; if a linear combination of lagged inflation and the output gap is a sufficient statistic for predicting future inflation, then Equation (3.8) reduces to the simple Taylor rule.

The monetary policy rule given by Equation (3.8) may be, however, too limited to describe actual changes in the short-term policy rate. It cannot capture the tendency of central banks to smooth changes in the interest rate. In order to allow for this behaviour, it is assumed that in many earlier studies the actual short-term nominal interest rate i_t adjusts toward the target interest rate i_t^T , according to a partial adjustment mechanism of the form:

$$i_t = (1 - \rho)i_t^T + \rho i_{t-1} + v_t, \quad (3.9)$$

where i_t^T is given by Equation (3.8), v_t is a zero-mean exogenous random shock to the interest rate, and the coefficient $\rho \in [0,1]$ measures the degree of smoothing in the central bank's response. Equation (3.9) means that in each period the central bank adjusts

⁷⁰ This information set contains all past realisations of inflation and the output gap.

⁷¹ As already shown in the previous subsection, this rule can also be derived in a framework where the central bank faces a quadratic loss function over inflation and output gap. See, for example, Bernanke and Woodford (1997); Svensson (1997); Martin and Milas (2009, 2010); and the references therein.

the *actual* policy rate to eliminate a fraction $(1 - \rho)$ of the gap between the current target level and its past values. Combining the target model (3.8) with the partial adjustment mechanism (3.9) leads to the estimable *forward-looking* policy reaction function:

$$i_t = (1 - \rho) [c + \theta(\pi_{t+k} - \pi^T) + \chi y_{t+l}] + \rho i_{t-1} + u_t, \quad (3.10)$$

where c is a constant parameter, *i.e.* $c = \bar{i}$, and

$$u_t = -(1 - \rho) [\theta(\pi_{t+k} - E\{\pi_{t+k} | \Omega_t\}) + \chi(y_{t+l} - E\{y_{t+l} | \Omega_t\})] + v_t, \quad (3.11)$$

which is an error term that is the sum of a linear combination of forecast errors of inflation and the output gap and a zero-mean exogenous interest rate shock, v_t . Equation (3.11) implies that forecast errors in curly brackets are orthogonal to the variables considered in the information set Ω_t . The notations of other parameters and variables are the same as in Equation (3.7). The forward-looking Taylor rule given in Equation (3.10) is now expressed in terms of *actual* values of variables instead of expected values. In practice, the central bank policymakers do not respond to the predetermined values of the key macroeconomic variables such as inflation and some measure of the output gap, as in the standard reaction function like Equation (3.7). Instead, they react to *forecasts* of those values. In this respect, Equation (3.10) is expected to be much more appropriate in explaining the central bank's behaviour than Equation (3.7).

3.4.3.3 Econometric Estimates

To examine the degree of smoothness of the observed policy interest rate and to assess the nature of actual policy-making in Korea, we can estimate the above rule equations which

take a partial adjustment form. For convenience, let us call Equation (3.7) the *modified* standard policy rule model, and Equation (3.10), the *forward-looking* policy rule model.

A. Data Description

The data set used here consists of quarterly time series for Korea spanning the period 1999:q2–2011:q4, covering the period of inflation targeting in Korea⁷². We employ the overnight call rate, headline CPI inflation, and real GDP (seasonally adjusted). The actual overnight call rate is the policy interest rate, i_t . CPI inflation is measured as the rate of change of the CPI (P_t) over the year: $\pi_t = [\ln(P_t) - \ln(P_{t-4})] * 100$. Correspondingly, the inflation target π^T for 1999 and 2000 is 3 and 2.5 percent, respectively, and it is 3 percent for each of the years from 2001 to 2011. The output (real GDP) gap y_t is measured as 100 times the proportional difference between the logarithm of an *ex-post* measure of actual real GDP and its Hodrick-Prescott (HP) trend which was calculated by using the smoothing parameter lambda (λ) = 1600. The call rate, real GDP and CPI series were obtained from the BOK database (ECOS).

B. The OLS Regression

In this subsection, we present estimates of the optimal monetary policy rule in (3.7). Table 3.5 reports least-squares estimates of the modified Taylor rule in (3.7) for the

⁷² In order to reflect that the BOK changed its target indicator from core CPI inflation to headline CPI inflation, we constructed a hybrid inflation gap, which consists of the core CPI inflation gap for the periods 2000:q1-2006:q4, and the headline CPI inflation gap for the period 1999:q3-q4 and for the period 2007:q1-2011:q4 (see Subsection 3.3.2.1 of Chapter 3).

period of 1999:q2–2011:q4 in quarterly frequency.⁷³ First of all, the policy rule is estimated with only the inflation gap and the output gap as explanatory variables. The first row (Model ①) provides estimates of the specification without partial adjustment ($\rho = 0$), which has severely serially correlated errors: the Durbin-Watson test shows that the absence of serial correlation is rejected. We estimated $\theta = -0.112$ and $\chi = 0.339$, indicating that the regression coefficient on the inflation gap is negative and statistically insignificant while that on the output gap is significant at the 1 percent level.

Next, the policy rule with the lagged variable of interest rate is estimated. The difference becomes more remarkable with the partial adjustment specification (Model ②) displayed in the second row of Table 3.5. The regression coefficient of ρ for quarterly data is close to 0.8, which confirms a considerably slow adjustment of interest rates in practice.⁷⁴ In the same way, we estimated $\theta = 0.05$ and $\chi = 0.135$, providing that the coefficient on the inflation gap is positive but statistically still insignificant while that on the output gap is significant at the 1 percent level. For each specification considered, the estimate of χ is always correctly signed, strongly statistically significant, while the estimate of θ is not statistically different from zero at conventional levels of significance. This is a somewhat weird result in that the central bank does not respond to the inflation. All told, the second model has a significantly better fit than the first one, even though the estimate of θ is not statistically significant.

⁷³ Similar estimations are conducted in other empirical studies using US data. See, for example, Sack (1998), Judd and Rudebusch (1998), Kozicki (1999), and Rudebusch (2002b).

⁷⁴ According to Sack and Wieland (2000), the size of the partial adjustment coefficient in the United States was about 0.8 for the period 1980:q1 to 1996:q4.

Table 3.5: Standard Modified Policy Rules Estimated by OLS, 1999:q2–2011:q4

	c	θ	χ	ρ	\bar{R}^2	SEE	DW stat.
Model ①	3.841*** (0.137)	-0.112 (0.130)	0.339*** (0.107)	–	0.15	0.95	0.28
Model ②	3.392*** (0.714)	0.050 (0.189)	0.135*** (0.016)	0.812*** (0.033)	0.94	0.26	1.45

Notes: 1. Asterisks *** denotes significance levels at 1 percent, and ** significance levels at 5 percent.
2. Figures in parentheses denote coefficient standard errors.

C. The GMM Approach

Assume that \mathbf{z}_t is a vector of instruments within the central bank's information set at the time policy rate decisions are made, *i.e.*, $\mathbf{z}_t \in \Omega_t$. As the elements of \mathbf{z}_t contain all past realised variables that are potentially useful for making forecasts of inflation and the output gap, as well as contemporaneous variables which are not correlated with the interest rate shock, v_t , Equation (3.10) discussed earlier implies a set of orthogonality conditions. More formally, since $E\{u_t|\mathbf{z}_t\}=0$, we have the following orthogonality conditions:

$$E\{i_t - (1 - \rho)[c + \theta(\pi_{t+k} - \pi^T) + \chi y_{t+l}] - \rho i_{t-1} | \mathbf{z}_t\} = 0, \quad (3.12)$$

which gives the prerequisite for estimating the parameter vector $\{\theta, \chi, c, \rho\}$, using the Generalised Method of Moments (GMM), with an optimal weighing matrix that accounts for possible serial correlation in u_t . Since the dimension of the vector \mathbf{z}_t is greater than the number of parameters being estimated, Equation (3.10) is overidentified, in which case it is therefore straightforward to test in order to assess whether the set of instruments

used is valid or not (Hansen, 1982)⁷⁵.

Following previous research, for example, Clarida *et al.* (1998), Peersman and Smets (1998), we take a target horizon of $l=0$ for the output gap, which means that central bank policymakers use current information to get the best estimate of the output gap at time t .⁷⁶ The target horizon for inflation, k is assumed to be 1 through 4 quarters. The instrument set contains 1, 2, 3 and 4 lags of variables: inflation gap, the output gap, and the call rate which are all available to policymakers.

Table 3.6 reports GMM estimates of the interest rate rule parameters $\{\tilde{\theta}, \tilde{\chi}, \tilde{c}, \tilde{\rho}\}$ in a standard forward-looking rule for Korea. The estimation results provide parameter values that are consistent with the results found in the literature (Clarida *et al.*, 1998 and 2000; Chadha *et al.*, 2004). The key result is the estimates of the coefficients on inflation, θ , which are always positively signed, strongly statistically significant, and greater than unity except for models ③ and ④. And the estimates of χ are also statistically significant at the 1 percent level. In particular, the estimates of θ are greater than those of χ , indicating a much stronger weight on inflation than on the output gap in Korea. And the regressive parameters of ρ are around 0.79~0.86, which reconfirms a markedly slow adjustment of interest rates as shown in OLS regression. Also, for all of these specifications, the overidentifying restrictions pass muster easily, *i.e.*, all the models pass the overidentification test provided that the p -value is higher than 5 percent. We cannot reject the overidentifying restrictions for all models. Therefore, the Hansen's J -test

⁷⁵ See Chadha *et al.* (2004) and Clarida *et al.* (1998) for the interpretation on the results of this test.

⁷⁶ The idea behind taking $l=0$ is that the current output gap contains information about future inflationary pressures so that central banks respond to the current output gap. In this case, central banks can be forward-looking even when reacting to the current output gap.

supports the validity of our specification and the instrument set used in this section. Nonetheless, the instruments used may be weak, meaning that they have a low correlation with the explanators. Adding a fifth or sixth lag of each variable to the instrument set has no large impact on the estimation results.⁷⁷

Table 3.6: Forward-looking Policy Rules Estimated by GMM, 1999:q2–2011:q4

	Model ③ ($k = 0$)	Model ④ ($k = 1$)	Model ⑤ ($k = 2$)	Model ⑥ ($k = 3$)	Model ⑦ ($k = 4$)
c	4.013*** (0.110)	3.056*** (0.658)	2.949*** (0.728)	3.188*** (0.584)	3.428*** (0.673)
θ	0.157 (0.213)	0.842** (0.318)	1.414*** (0.362)	2.093*** (0.369)	1.124** (0.555)
χ	0.067*** (0.011)	0.235*** (0.024)	0.204*** (0.029)	0.088*** (0.019)	0.129*** (0.023)
ρ	–	0.847*** (0.028)	0.860*** (0.026)	0.830*** (0.025)	0.792*** (0.030)
\bar{R}^2	0.013	0.901	0.903	0.864	0.893
J-test (p -value)	0.244	0.355	0.358	0.487	0.478

Notes: 1. The instrument set includes a constant, 1, 2, 3, 4 lags of variables: inflation gap, the output gap, and the call rate.
2. Estimates are obtained by GMM with the optimal weighing matrix obtained from the White method.
3. Standard errors are shown in parentheses.
4. Asterisks (***) indicate that the null hypothesis is rejected at the 1 percent significance level.
5. J-test is the test for overidentifying restrictions (Hansen, 1982), which is distributed as χ^2 under the null hypothesis (no overidentification). For this test, only p -values are reported.

3.4.4 Why do Central Banks Smooth Interest-rates?

While the modification approaches taking into account a partial adjustment term discussed above can explain some portion of interest-rate smoothing, they do not explain

⁷⁷ In order to check for possible presence of weak instruments, we performed an F -test applied to the first-stage regression: the results confirm that the instruments used are relevant: for the model ⑦, F -statistic = 32.1, with a p -value = 0.047. The F -tests for the remaining models yield similar results which are not reported here.

sufficiently enough the observed autocorrelation of policy interest-rate movements. As DeBelle and Cagliarini (2000) stated, such modifications are also somewhat unsatisfactory since they are *ad hoc*.

In the real world, it is no wonder that central bank policymakers consider the current values of macroeconomic variables, such as inflation and real output, as well as their evolving behaviour in formulating current and future policy choices. Macroeconomic variables, however, respond to monetary policy with a considerable lag and show a strong serial correlation, so that smoother path in the key policy rate might be expected to some extent even in the absence of an interest-rate smoothing incentive (Sack, 2000).

Consequently, more explicit identification and explanations for the smoothing pattern of interest-rate movements are needed. Indeed, a number of possible explanations for the observed smoothness of policy interest rates were suggested. It is sometimes argued that central banks' behaviour in moving policy interest rates in a gradual and predictable way reflects to a large extent the optimal response to various shocks and the dynamic behaviour of the macroeconomic variables.

In this subsection, we briefly discuss four strands of argument to explain why the observed degree of interest-rate smoothing may be optimal behaviour on the part of central banks.

Policy Effectiveness

The first argument for interest-rate smoothing is based on the effect of the short-term interest rates on the aggregate demand through the effects on long-term interest rates. Insight into why gradual target adjustments of limited size in the same direction may be

optimal for central banks is initially provided by Goodfriend (1991), and also endorsed by Rudebusch (1995). This argument is refined by Rotemberg and Woodford (1997) and by Woodford (2000 and 2003b). Goodfriend (1991) argues that prices and real output respond to changes in long-term interest rates rather than to daily fluctuations in the short-term policy rates. Central banks attempt to attain their stabilisation goals by targeting their policy instrument rate so as to affect long-term market rates. Rotemberg and Woodford (1997) give an explanation for interest-rate smoothing: their idea is that inertial monetary policy allows central banks to affect the long-term interest rate, and hence aggregate demand, with more modest movements in the short-term rates than would otherwise be needed. This kind of adjustment rule is thus desirable because central banks may want to avoid excessive fluctuations in short-term interest rates. In the same context, Woodford (2000 and 2003b) argues that policy inertia makes the future path of short-term interest rates more predictable and thus increases effectiveness in policy-making.

If central banks' policy shows a high degree of persistence, and thus their reputation for moving policy instruments in a gradual manner is established and intact, a forward-looking private sector will anticipate a small change in the short-term interest rate to be followed by further adjustments without reversing direction for some time. If such expectations are well formulated, then central banks can achieve their goals to stabilise inflation and output without excessive volatility in short-term interest rates (see also Rudebusch, 1995; Sack and Wieland, 2000; and Castelnuovo and Surico, 2004).

Financial (Market) Stability

A second explanation relies on the fact that a gradual policy move may reduce risks to financial market stability. Some researchers argue that a pattern of gradual adjustment reflects the attention that central banks pay to promoting financial stability. Cukierman (1991) shows that when commercial banks pay a flexible interest rate on deposits while receiving fixed payments for loans, high volatility in interest rates may trigger bank failures since their liabilities may exceed their available assets. Therefore, gradual moves of the short-term policy rate by the central bank allow commercial banks to adjust smoothly to changes in the costs of short-term funding, thus leading to the increasing stability of bank profits. Slow adjustment of short-term rates can reduce financial stress for businesses with a great need for short-term financing as well. In the same context, Sinclair (2000) argues that sharp and large changes in short nominal interest rates may add to uncertainties in financial markets. In particular, when policy is delayed, the magnitude and duration of the alterations in short nominal rates are greater than would otherwise be the case. In this case, interest rate swings tend to increase the likelihood of business failures, and subsequently bring about a negative impact on the balance sheets of banks in periods of a credit crunch. This is because a low degree of interest-rate smoothness may cause excess volatility in financial markets. In contrast to this case, timely and modest adjustments in interest rates can contribute significantly to long-run financial market stability.

More specifically, Bernanke (2004) points out that central banks choose to alter interest rates moderately to avoid the risk of shocking the bond market. Sharp changes in the short-term policy rate and the resulting large movements in long-term rates due to their

implications for private-sector expectations about the future path of short-term rates may risk generating wide swings in bond prices and thereby potentially large capital gains or losses for bondholders. As a consequence, they can pose high risks for financial sectors such as banks and other financial institutions that hold bonds, further increasing financial market volatility. Hence, in order to keep financial markets orderly and well-functioning, other things being equal, central banks tend to come to choose policies that preclude undue stress on financial markets (Rudebusch, 1995; Cobham, 2003).⁷⁸

The Central Bank's Reputation

This explanation states that frequent changes in the direction of interest rates make central bank policymakers look poorly-informed, accordingly lowering their credibility. Caplin and Leahy (1997) emphasise that if the central bank lacks credibility, frequent reversals in interest rates could further undermine confidence in it. Goodhart (1999a) also argues that central bankers do not like to take the risk of making reversals in interest rates, which he relates to the difficulty of explaining to outside observers why the monetary policy stance is determined by something approaching a so-called random walk.⁷⁹ Given the random walk nature of news about inflation and output, there is a considerable chance that an interest rate change that is optimal today will have to be reversed tomorrow (Eijffinger *et al.*, 1999). This might give the public the impression that the central bank is badly-informed as to the relevant policy directions, thereby provoking

⁷⁸ Nevertheless, Bernanke (2004) states that even if the financial-stability argument has some merit, the case is not as straightforward as it may seem at first: a problem with the argument is that policy gradualism does not necessarily insulate bondholders from capital gains and losses.

⁷⁹ Lowe and Ellis (1997) state that a smoother interest rate path is easier for the central bank to explain to the wider public.

criticism. Therefore, policymakers may avoid large swings in interest rates in response to unforeseen developments in the economy, in order to maintain credibility and safeguard their reputation.

Uncertainty

The most persuasive argument for why central banks choose a more gradual path of interest rates than theory would predict is that monetary policy decisions are undertaken in a largely uncertain environment. Uncertainty about the current state and the structure of the economy can lead to slower response of the interest rate to current or future shocks. Notwithstanding the progress in macroeconomic modelling, developments in economic conditions and especially in the highly integrated global environment, pose difficulties for central banks' policy-making. As Goodhart (1999a) points out, the uncertainty that central banks face in practice is so complicated and pervasive that it cannot be expressed by the additive error terms alone in standard models.

A large number of existing papers have argued that monetary policy gradualism may be justified if there are various uncertainties over the key relationships between involved variables and/or relevant economic data⁸⁰. Highlighting the significance of uncertainty as a rationale for gradual adjustment in setting the policy rate, Bernanke (2004) remarks that:

Many central bankers and researchers have pointed to the pervasive uncertainty associated with analysing and forecasting the economy as a reason for central banks' caution in adjusting policy. Because policymakers cannot be

⁸⁰ See, for example, Goodhart (1999a), Sack (2000), Martin and Salmon (1999), and others.

sure about the underlying structure of the economy or the effects that their actions will have on economic outcomes, and because new information about the economic situation arrives continually, the case for policymakers to move slowly and cautiously when changing rates seems intuitive.

To sum up, in a variable and uncertain world, monetary policymakers do not know the exact impact that policy changes will have on inflation and real economic activity. And, it is difficult for them to assess with precision the current state of the economy (data uncertainty). Moreover, they do not know the true structure of the economy perfectly (parameter or model uncertainty).

3.5 Conclusion

This chapter has dealt with some stylised facts in policy rate adjustment practices and has attempted to present the empirical evidence that gradual adjustment behaviour exists for the policy interest rates in Korea.

As in the advanced countries, some salient features in the policy interest rate path have appeared in Korea: *(i)* infrequent moves in the policy interest rate; *(ii)* successive changes of the interest rate in the same direction; *(iii)* asymmetric adjustments in terms of the size of interest-rate changes for continuation and reversal periods; and *(iv)* a long pause before reversals of the policy interest rate. These patterns are referred to as ‘interest-rate smoothing’, which is regarded as an appropriate result for developments in macro-economic conditions, particularly in the highly integrated global environment,

where central bank policymakers inevitably have great difficulty in setting the policy interest rate.

As a result of estimation of policy reaction rule equations using the OLS and GMM techniques, the regression coefficients of partial adjustment term, the lagged interest rate variable turns out to be around 0.80~0.86, indicating a considerably slow adjustment of the interest rate for quarterly data in practice in Korea. Likewise, we found that the modification approaches having a partial adjustment term as a third argument in the policy reaction function could explain interest-rate smoothing to some extent. As shown in Subsection 3.4.3, monetary policy rules augmented with a partial adjustment term can be optimal at conducting monetary policy.

It seems, however, that such augmented policy rules are not in themselves sufficient to explain the autocorrelation of policy interest rate movements. For this reason, we attempted to investigate more explanations for the smoothing movements. Some degree of interest-rate smoothing may be desirable or optimal. Central bank policymakers could deviate from the equilibrium interest rate randomly, or set their policy instruments such that there was the same probability of the next adjustment being up or down. But this sort of policy choice is not likely to be optimal. Rather, optimal policy might lead to systematically positive autocorrelations in changes of the key policy rate.

The arguments surveyed in this chapter to explain the reasons why the observed degree of interest-rate smoothing may be optimal behaviour on the part of central banks are: (i) enhancing central banks' policy effectiveness; (ii) maintaining financial (market) stability; (iii) safeguarding the central bank's credibility and reputation; and (iv) central

banks' confronting uncertainty in conducting monetary policy. In this way, central banks' smoothing of policy interest rates may be optimal behaviour for a variety of reasons, not least of which is that monetary policy is conducted in a largely uncertain world. When formulating the policy strategy and choosing interest-rate levels, central bank policymakers are always confronted with considerable uncertainty regarding the evolution of economic activity. Furthermore, they may be uncertain about the effect of their policy actions on the ultimate goal variables such as inflation and real output.

In this chapter, we showed that the degree of interest-rate smoothing can be optimal through theoretical derivation of policy reaction function with a partial adjustment term. Yet, the task of thoroughly assessing whether or not the interest-rate smoothing seen in actual policy-making is optimal lies beyond the scope of this chapter. The impact of uncertainty on the operation of monetary policy in Korea, and the optimal interest rate settings will be discussed in more detail in the following two chapters, 4 and 5.

Chapter 4

Monetary Policy under Parameter Uncertainty in Korea: a VAR Approach

4.1 Introduction

Diverse uncertainties are rife in the economy, and thus they influence the behaviour of monetary policymakers. Economic conditions have a tendency to change over time in response to various external shocks. Accordingly, there are a lot of difficulties in conducting efficient monetary policy. Even though policymakers try to reduce economic instability in the face of uncertainty, it is impossible for them to cope with it immediately and completely. The econometric models central banks rely on have a limitation in reflecting the actual economy's dynamics sufficiently as well as forecasting the movements of key economic variables exactly. After all, the presence of uncertainty shortens the scope of policy choices that policymakers can make in the real economy.

During the early 1960s, a number of studies on the effect of uncertainty on

monetary policy were conducted. However, such studies have not received much attention, because they assume there is solely additive uncertainty under which the certainty equivalence principle holds. Unlike additive uncertainty, multiplicative uncertainty is known to affect the process of optimal policy-making. According to the existing literature, under additive uncertainty, the policymakers can achieve the objective of the central bank by setting their interest rates in an active fashion. In contrast, multiplicative uncertainty such as parameter uncertainty, which is the uncertainty on the monetary transmission mechanism, induces the policymakers to prefer conservative monetary policy reaction when deciding the interest rate instrument.

In formulating monetary policy, it is very important that central banks should take into consideration uncertainty coming from diverse matters related to the evolving economic situations. According to the Brainard conservatism principle (BCP) discussed in Chapter 2, the central bank ought to exhibit more conservative behaviour in its formulation of policy in the presence of multiplicative uncertainty. This tendency can be found in the adjustment of policy interest rates in the US and other major developed countries. For instance, the US Federal Funds rate has been adjusted gradually and cautiously. This fact implies that the Fed's interest rate policy poses a timid pattern of movements, compared to that derived under the absence of uncertainty. This feature tends to be notable especially when policy rates need to be adjusted in the opposite direction.

As already explained in Chapter 3, an inflation targeting (IT) regime in Korea was adopted in the aftermath of the Korean currency crisis of 1997–1998. As a result, the Bank of Korea (BOK) shifted the instrument of monetary policy from monetary aggregates to interest rates. The BOK has historically carried out monetary policy

adjustments in a gradual fashion. Indeed, the BOK is judged to have kept a conservative posture in moving the Bank of Korea Base Rate, the equivalent of the US Federal Funds rate target, since the implementation of interest rate-oriented monetary policy. However, there is a lack of research supporting this finding concerning the movements in policy interest rates under uncertainty in Korea.

The objectives of this chapter are threefold: the first objective is to investigate whether gradual movements in policy rates (conservatism) can be explained quite a few by the existence of parameter uncertainty even in the absence of the interest-rate smoothing motive in the central bank's objective function. The focus on the conservatism might be justified by the attempt of explaining interest-rate smoothing behaviour by the central bank; the second one is to examine the effect of parameter uncertainty upon monetary policy in Korea. As discussed in the literature review, it is often accepted that it is desirable to adjust policy instruments gradually in the presence of uncertainty; and the last is to assess the role of actual monetary policy conducted by the BOK in an uncertain environment since the adoption of inflation targeting in the late 1990s.

The main findings of this chapter are: firstly, uncertainty can provide a rationale for the central bank to smooth its policy interest rates in Korea. In particular, since the introduction of an interest rate-oriented monetary policy in the late 1990s, the actual policy rate (say, the call money rate) has shown similar movements of the optimal rate under parameter uncertainty. Therefore, the analysis result suggests that monetary policy has been implemented in a similar fashion to the optimal policy derived under the assumption that such uncertainty exists; secondly, in the absence of parameter uncertainty, the calculated optimal policy rule responds more actively to changes in the economy than the

actual policy rule, leading to higher fluctuations in policy rates than the actual rule; and thirdly, gradual movements in the policy rates do not necessarily mean that the central bank has an objective function with an explicit interest-rate smoothing incentive. Uncertainty and the dynamic structure of the economy can account for a considerable portion of the observed gradual movements of interest rate.

The remainder of the chapter proceeds as follows. Section 4.2 discusses the theory and methodology employed for analysis on the optimal monetary policy rules under additive and parameter uncertainty. The model used here for solving dynamic programming problems is almost identical to the framework used by Sack (2000), taking a vector-autoregressive (VAR) model of the economy and deriving the optimal rules under alternative assumptions as to the presence of uncertainty. Section 4.3 describes the data for empirical analysis, and provides some empirical issues such as the VAR model identification and policymakers' preference weights. In particular, this section expounds identifying restrictions on the VAR model. The VAR identification for the conduct of impulse response analyses follows the structural VAR model, not the unrestricted VAR. Section 4.4 sets out empirical results. This section compares optimal policy rules under different uncertainties, and then shows the impulse responses of policy interest rates to economic shocks in the presence of uncertainties for the Korean economy. Lastly, Section 4.5 concludes the chapter and draws out possible implications for monetary policy in Korea.

4.2 Theory and Methodology

This section discusses the consequences of parameter uncertainty for optimal monetary policy in an inflation targeting framework in a closed economy by employing a stylised

model in the literature (Svensson, 1997 and 1999a; Rudebusch and Svensson, 2002; Rudebusch, 2001 and 2005).

4.2.1 Parameter Uncertainty under Inflation Targeting: a Static One-period Problem

4.2.1.1 The Structure of the Economy

First of all, prior to examining how parameter uncertainty has an impact on monetary policy, let us consider the following two equations: a backward-looking Phillips curve and an IS curve:

$$\pi_t = \alpha \pi_{t-1} + \beta y_{t-1} + \varepsilon_t^s, \quad (4.1)$$

and

$$y_t = \phi y_{t-1} - \psi r_t + \eta_t^d, \quad (4.2)$$

where autoregressive coefficients α and ϕ fulfill $0 \leq \alpha, \phi < 1$, and the parameters β and ψ are positive. And the error terms ε_t^s and η_t^d are *i.i.d.* innovations with the means zeros and variances σ_ε^2 and σ_η^2 , respectively. All variables are expressed in percentage deviations from their steady-state values. It is assumed that the inflation gap and the output gap at equilibrium state (say, the targets for the inflation gap and the output gap, respectively) are normalised to zero, and so is the equilibrium real interest rate.⁸¹ In Equation (4.2), therefore, the real interest rate gap, r_t , is just defined as the subtraction of equilibrium real interest rate from the difference between the short-term nominal

⁸¹ The equilibrium real interest rate, r^n is defined as the rate consistent with the output being at the natural rate and inflation being at its target.

interest rate, i_t (*i.e.*, the central bank's policy instrument) and expected inflation over the $t+1$, $E_t\pi_{t+1}$ by the Fisher identity, *i.e.*, $r_t = i_t - E_t\pi_{t+1}$. This term is a simple representation of the monetary policy transmission mechanism⁸² for the central bank (Rudebusch and Svensson, 1999).

In fact, both equations are fairly general models in the literature: Equation (4.1) assumes that inflation depends on the lagged values of inflation and the output gap, and (additive) supply shocks, ε_t^s ; and Equation (4.2) assumes that the output gap is affected by the lagged output gap, the real interest rate and (additive) demand shocks, η_t^d .

For simplification of the discussion, following Martin and Salmon (1999), assume $\phi = 0$. And, then eliminating the output gap, y_t , in Equation (4.1) and (4.2) gives:

$$\pi_t = \alpha\pi_{t-1} - br_{t-1} + u_t, \quad (4.3)$$

where $b = \beta\psi > 0$ and $u_t = \beta\eta_{t-1} + \varepsilon_t$. Equation (4.3) gives the basic reduced-form process for inflation. The last additive term, u_t , assumed to obey *i.i.d.* with zero mean and variance, σ_u^2 , is interpreted as contemporary shocks confronted by central bank policymakers. But they do not observe those shocks. In Equation (4.3), the parameter $\alpha > 0$ measures the inflation persistence, and the parameter $b > 0$ captures the policy multiplier effect in the model.

The central bank chooses the nominal interest rate, i_t , with the aim of attaining the inflation target. To do so, it needs to compute the desired monetary policy stance and the

⁸² The interest rate channel is the key monetary policy transmission mechanism in the basic Keynesian model. Of course, there are a variety of channels relating to movements in asset prices such as exchange rates, real estate prices, and the so-called credit channel (Mishkin, 1995).

associated expectation of inflation. Assume that the central bank knows with certainty the parameter values (α and b) describing the relationship between variables in the economy. The optimal rule for real interest rates in response to deviations of inflation from its target, can then be determined⁸³:

$$r_t^{op} = \frac{\alpha}{b} \pi_t. \quad (4.4)$$

This policy rule is certainty-equivalent optimal reaction function in an economy with no uncertainty about additive shocks. To understand the dynamic path of the real interest rate in this model and its implications, it is worth finding the equilibrium process for inflation. This can be obtained by plugging (4.4) into (4.3) to yield:

$$\pi_t = u_t. \quad (4.5)$$

Equation (4.5) is the inflation process for the central bank's desired path for the real interest rate. This equation implies that inflation is driven solely by the new shock in each period. Given this equilibrium inflation process, the corresponding desired path for the real interest rate is expressed as a linear function of additive shocks to the economy:

$$r_t^{op} = \frac{\alpha}{b} u_t. \quad (4.6)$$

In practice, the central bank moves the nominal interest rate to achieve its policy

⁸³ The central bank's problem is equivalent to minimising expected squared inflation deviations from its target:

$$\min E_t \pi_{t+1}^2 = E_t (\alpha \pi_t - b r_t + u_{t+1})^2$$

Taking the partial derivative with respect to r_t and setting the result equal to zero, we have:

$$r_t^{op} = \frac{\alpha}{b} \pi_t.$$

objective. Given the desired path of the real interest rate, the policymaker sets the nominal interest rate equal to the desired real interest rate plus expected inflation:

$$i_t^{op} = r_t^{op} + E_t \pi_{t+1} = \frac{\alpha}{b} u_t. \quad (4.7)$$

Notice that since $E_t \pi_{t+1} = E_t u_{t+1} = 0$ under additive uncertainty, inflation expectations at time t are zero. Therefore, the nominal interest rate is equal to the real rate, implying that the nominal interest rate moves only in response to the shock.

Following this rule, the central bank could accurately offset the impact of external shocks upon inflation. Hence, the next period's inflation expectation at time t would always be the same as its target.

In this simple model, parameter uncertainty arises when policymakers do not know how changes in one variable are supposed to affect another. Assume that the central bank knows the functional form of the economy, but does not know the magnitude of policy multiplier, b . Then, he will be uncertain how changes in real interest rates would have an impact on inflation through movements in the output gap. The effect of parameter uncertainty on monetary policy will be discussed below.

4.2.1.2 The Central Bank's Objective Function and Optimal Policy

Following Svensson (1997 and 1999a), consider the simple version of the inflation targeting problem. Inflation targeting is interpreted as monetary policy conducted by central banks with a long-run inflation target, and in the short-run central banks want to reduce inflation variability around the long-run inflation target; inflation rate stabilisation is only one goal in the objective function. But, inflation targeting may in practice be

understood by central banks as involving additional goals such as output or employment stabilisation. Suppose the central bank faces the following intertemporal optimisation problem; the central bank's objective is to minimise the expected discounted sum of future value of a loss function, which is quadratic in the inflation gap and the output gap deviations from their respective targets subject to the constraint as implied by Equation (4.3), which is given by:

$$\min_{\{i\}} E_t \sum_{k=0}^{\infty} \delta^k L_{t+k}, \quad (4.8)$$

where

$$L_t = \frac{1}{2} [(\pi_t - \pi^T)^2 + \lambda (y_t - y^T)^2] \quad (4.9)$$

where $E_t(\cdot)$ represents expectations conditional on the set of all relevant information (Ω_t^{CB}) available to the central bank at time t . The parameter, δ , is the central bank's relevant discount factor satisfying $0 < \delta < 1$. π_t and π^T are the inflation rate gap at time t and the inflation gap target, respectively (normally, π^T is assumed to be 0). And, y_t is the output gap defined as the difference between the level of actual output and its potential, estimated under the assumption of full utilisation of resources and y^T is its target (normally, assumed to be 0). The parameter, λ , with a positive value denotes the subjective weight assigned to stabilising the output-gap relative to stabilising inflation⁸⁴. Therefore, parameters $(1, \lambda)$ for each goal variable reflect the central bank's preferences. As defined in Svensson (1999a), a "strict" inflation targeting refers to the case where

⁸⁴ Note that λ is a parameter which determines the degree of flexibility in inflation targeting. Therefore, when $\lambda = 0$, the central banker is a strict inflation targeter.

only the inflation goal enters the loss function, which implies that $\lambda = 0$, while a “flexible” IT allows other goal variables, that is, $\lambda \neq 0$.

It is assumed that policymakers do not know the exact values of parameters in Equation (4.3), but they know means $E(\alpha)$ and $E(b)$, and variances $Var(\alpha)$ and $Var(b)$ of the parameters. Hence, the policymakers determine the policy choices based on a *prior* belief about the probability distribution of parameters α and b . To examine how uncertainty about the parameter b influences the monetary policy stance, however, consider the case, $\pi_t = \alpha\pi_{t-1} - br_{t-1} + u_t$, assuming that $\alpha \sim N(\bar{\alpha}, \sigma_\alpha^2)$, $b \sim N(\bar{b}, \sigma_b^2)$, $u_t \sim N(0, \sigma_u^2)$, and $Cov(\alpha, b) = \rho^{ab}\sigma_\alpha\sigma_b = 0$, where ρ^{ab} is the correlation coefficient and σ_α and σ_b are standard deviations of parameters α and b , respectively. The problem in this kind of multi-period model can be solved using the dynamic programming method. But, following Svensson (1997 and 1999a), the solution to this simple case can be obtained by solving a sequence of one-period problems⁸⁵ where the central bank’s objective function to be minimised in each period is:

$$\min \frac{1}{2} \{E_t \pi_{t+1}^2 + \lambda y_{t+1}^2\} \quad (4.10)$$

or

$$\min \frac{1}{2} \{[E_t \pi_{t+1}]^2 + Var_t(\pi_{t+1}) + \lambda y_{t+1}^2\} \quad (4.11)$$

In turn, this equation implies that the policymaker cares about the variance of inflation

⁸⁵ According to Svensson (1997, p. 1117), the multi-period problem reduces to a sequence of one-period problems where the current period’s interest rate is assigned to returning the next period’s inflation rate to the target. In other words, as the interest rate affects the inflation rate with a one-period lag, r_t will have an impact on the inflation rate only in period $t+1$, $t+2$, ..., and r_{t+1} will influence the inflation rate only in period $t+2$, $t+3$, ..., and so on. Hence, the central bank can find the optimal interest rate in period t as the solution to the simple period-by-period problem.

(uncertainty about future inflation) as well as the bias in inflation (expected deviations of future inflation from its target, π^T)⁸⁶. For simplification, assume $\lambda = 0$, *i.e.*, that a central banker is a *strict* inflation targeter (one-target and one-instrument case). And since $E_t(\pi_{t+1}) = \bar{\alpha}\pi_t - \bar{b}r_t$ and $Var_t(\pi_{t+1}) = \sigma_a^2\pi_t^2 + \sigma_b^2r_t^2 + \sigma_u^2$, Equation (4.11) can be rewritten as:

$$\min \frac{1}{2} \{ [\bar{\alpha}\pi_t - \bar{b}r_t]^2 + \sigma_a^2\pi_t^2 + \sigma_b^2r_t^2 + \sigma_u^2 \}. \quad (4.12)$$

Then, the optimal policy rate in the presence of parameter uncertainty, r^{op} , which minimises the loss function (4.12), can be obtained as follows:

$$r_t^{op} = \frac{\bar{\alpha}\bar{b}}{\bar{b}^2 + \sigma_b^2} \pi_t. \quad (4.13)$$

Equation (4.13) implies that as the degree of uncertainty about a parameter b increases, the central bank should react less vigorously to the policy instrument relative to the case where there is no parameter uncertainty. This result reflects Brainard's insight that the optimal policy reaction should take account of the uncertainty about policy multiplier in the transmission mechanism.

Throughout the chapter, it is important to note that the objective function does not include any explicit reason to smooth interest rates, since the purpose of this research is to examine whether gradual adjustment in interest rates can be explained even in the absence of the assumption that the central bank prefers to act less aggressively.

⁸⁶ This is a result of Jensen's inequality, which implies that the expected squared value of a variable equals the square of the bias plus the variance: $E(x^2) = [E(x)]^2 + Var(x)$.

4.2.2 The Optimal Policy Rules under Parameter Uncertainty: a Dynamic Multi-period Problem

The models we set up here follow Sack (2000) who, by using a VAR, incorporates initially additive uncertainty, and then parameter uncertainty into the optimisation problem. The heart of this approach is to allow interest rates to have an influence on the economy over a number of periods under uncertainty, and to calculate the variance-covariance matrix for the coefficients indicating the extent of parameter uncertainty.

4.2.2.1 The VAR Model

The static one-period case we discussed in Subsection 4.2.1 is a simple model comprising inflation and interest rate variables. In a VAR, we model an n -vector of endogenous variables including inflation, which follows a linear autoregressive process with q lags. Correspondingly, this approach reflects uncertainty about more parameters than the simple model discussed in the previous subsection.

In order to answer the question of how the central bank conducts monetary policy in the face of uncertainty, first of all, suppose that the economy can be described by the following linear structural VAR model:

$$\mathbf{B}_0 \mathbf{Y}_t = \mathbf{C} + \sum_{i=1}^q \mathbf{\Gamma}_i \mathbf{Y}_{t-i} + \mathbf{D} \boldsymbol{\mu}_t, \quad (4.14)$$

where boldface letters are used to denote vectors or matrices of variables or coefficients, and the subscript q is the number of lags in the VAR system. \mathbf{Y}_t is an $(n \times 1)$ vector of the state variables predetermined at time t . Assume, for example that the state vector is

given by $\mathbf{Y}_t = [y_t, \pi_t, i_t]'$, in which each element corresponds to the output gap, the rate of inflation and policy interest rates, respectively. \mathbf{B}_0 is an $(n \times n)$ coefficient matrix which tells us how the endogenous variables are contemporaneously linked to each other. The identification of this matrix allows us to understand the relation between the structural and reduced form of VAR. $\mathbf{\Gamma}_i$ is an $(n \times n)$ coefficient matrix for the lagged variables. And, $\boldsymbol{\mu}_t$ is an $(n \times 1)$ vector of *i.i.d.* $N(0, I)$ correlated structural shocks. \mathbf{C} denotes an $(n \times 1)$ vector containing all the deterministic components (if any). \mathbf{D} is an $(n \times n)$ matrix that contains zeros except for the main diagonal elements with ones.

Unfortunately, we cannot estimate this system of equations directly due to identification issues, but it is possible to transform this system into a reduced-form representation of \mathbf{Y}_t :

$$\mathbf{Y}_t = \mathbf{Q} + \sum_{i=1}^q \boldsymbol{\Phi}_i \mathbf{Y}_{t-i} + \mathbf{e}_t, \quad (4.15)$$

where $\mathbf{Q} = \mathbf{B}_0^{-1} \mathbf{C}$, $\boldsymbol{\Phi}_i = \mathbf{B}_0^{-1} \mathbf{\Gamma}_i$, and $\mathbf{e}_t = \mathbf{B}_0^{-1} \mathbf{D} \boldsymbol{\mu}_t$. \mathbf{Q} is an $(n \times 1)$ vector of deterministic components. An additive term \mathbf{e}_t is a reduced-form VAR pure innovation vector (*i.i.d.* $N(0, \Omega)$). Now we can estimate the random stochastic residuals $\mathbf{B}_0^{-1} \mathbf{D} \boldsymbol{\mu}_t$ from the mutually uncorrelated regression residual \mathbf{e}_t of the reduced form of VAR.

Correct identification of the structural model (4.14) gives n structural equations with the additive vector $\boldsymbol{\mu}_t$ of disturbances to the VAR system. That is, we get the first $n-1$ equations describing the dynamic structure of the economy. Given this estimated

dynamic behaviour of the non-policy variables, we can estimate the n -th equation, the policy reaction function that shows how the optimal path of policy rate depends on current and lagged non-policy variables and lagged policy variables, as well as on additive shocks.

4.2.2.2 Calculation of Optimal Policy Rules with Additive Uncertainty

The central bank's objective function, for simplicity, can be rewritten in a quadratic matrix form in the state and control variables. The fully-specified linear-quadratic control problem is given below:

$$L = \min_{\{i_t\}} \frac{1}{2} E_t \left\{ \sum_{k=1}^{\infty} \delta^k (X_{t+k} - X^*)' R (X_{t+k} - X^*) \right\}, \quad 0 < \delta < 1, \quad (4.16)$$

where $E_t(\cdot)$ denotes the expected value operator conditional on time t information; X^* is a vector which is composed of the targets of the state variables; and the symmetric matrix R represents a weight that the central bank places on each state variable and contains zeros except for the diagonal elements corresponding to the contemporaneous output gap and inflation rate. That is, R summarises the preferences of the policymaker by assigning weights to each policy objective.

To solve the dynamic programming problem, let $X_t = [y_t, y_{t-1}, \dots, y_{t-q}; \pi_t, \pi_{t-1}, \dots, \pi_{t-q}; i_{t-1}, \dots, i_{t-q}]'$ be the vector of predetermined state variables at time t . This vector set includes all current and lagged values of the non-policy variables and lagged values of the policy interest rates. Then, the state-space representation of the economy is given by:

$$X_{t+1} = AX_t + Bi_t + J + \xi_{t+1}. \quad (4.17)$$

In Equation (4.17), which is called a transition equation, the linear dynamics of the state variable vector are determined by the matrix A and the vectors B and J , whose elements are comprised of the point estimates of the coefficients from the VAR model described above. More specifically, the matrix A denotes the dynamic structure of the model and the vector B describes how the economy responds to the policy instrument. Uncertainty is embedded in the form of an *additive* vector ξ_{t+1} . In the analysis under additive uncertainty, policymakers are assumed to know for sure the dynamic structure of the economy, to such an extent that they regard the point estimates obtained from the VAR estimation as being the “true” parameters. Therefore, when incorporating additive uncertainty into the model, certainty equivalence holds.

Let $V(X_t)$ denote the value function at time t . The optimal policy of the central bank is to solve the following Bellman equation⁸⁷:

$$V(X_t) = \min_{\{i_t\}} \frac{1}{2} \left\{ (X_t - X^*)' R (X_t - X^*) + \delta E_t[V(X_{t+1})] \right\}, \quad (4.18)$$

subject to $X_{t+1} = AX_t + Bi_t + J + \xi_{t+1}$.

where some notations are repeated here for convenience: R is an $(n \times n)$ symmetric matrix of a weight of the state variables; X_t an $(n \times 1)$ vector of the state variable; i_t a $(k \times 1)$ vector of the control variable; A an $(n \times n)$ matrix; B an $(n \times k)$ matrix; J an $(n \times 1)$ vector of constants; and ξ_{t+1} an $(n \times 1)$ vector of random shocks.

We know that since the objective function is quadratic and the constraint is linear,

⁸⁷ See Ljungqvist and Sargent (2000), Chapter 4 of “*Recursive Macroeconomic Theory*”; and Sack (2000) for the methods solving this Bellman equation of dynamic programming.

the value function will be of the form:

$$V(\mathbf{X}_t) = \mathbf{X}_t' \mathbf{P} \mathbf{X}_t + 2\mathbf{X}_t' \boldsymbol{\omega} + d, \quad (4.19)$$

where \mathbf{P} is a symmetric matrix, $\boldsymbol{\omega}$ is a vector and d is a scalar, all of them yet to be determined. In particular, since \mathbf{P} is idempotent, $\mathbf{P}' = \mathbf{P}$.

For the sake of simplicity, we drop the time subscripts. In all cases, \mathbf{X} and i refer to time t dated variables. Then, substituting the form of the value function (4.19) into the value function (4.17) to eliminate the next period's state, \mathbf{X}_{t+1} , the Bellman equation is given by:

$$\begin{aligned} V(\mathbf{X}) &= \mathbf{X}' \mathbf{P} \mathbf{X} + 2\mathbf{X}' \boldsymbol{\omega} + d \\ &= \min_{\{i\}} \left\{ (\mathbf{X} - \mathbf{X}^*)' \mathbf{R} (\mathbf{X} - \mathbf{X}^*) + \delta E \left[\begin{aligned} &(\mathbf{A}\mathbf{X} + \mathbf{B}i + \mathbf{J} + \boldsymbol{\xi})' \mathbf{P} (\mathbf{A}\mathbf{X} + \mathbf{B}i + \mathbf{J} + \boldsymbol{\xi}) \\ &+ 2(\mathbf{A}\mathbf{X} + \mathbf{B}i + \mathbf{J} + \boldsymbol{\xi})' \boldsymbol{\omega} \end{aligned} \right] + \delta d \right\}. \end{aligned} \quad (4.20)$$

Expanding the quadratic terms in brackets, while remembering that $(\mathbf{A}x)' = x' \mathbf{A}'$ gives:

$$V(\mathbf{X}) = \min_{\{i\}} \left\{ \begin{aligned} &(\mathbf{X} - \mathbf{X}^*)' \mathbf{R} (\mathbf{X} - \mathbf{X}^*) \\ &+ \delta E \left[\begin{aligned} &(\mathbf{X}' \mathbf{A}' \mathbf{P} \mathbf{A} \mathbf{X} + \mathbf{X}' \mathbf{A}' \mathbf{P} \mathbf{B} i + \mathbf{X}' \mathbf{A}' \mathbf{P} \mathbf{J} + \mathbf{X}' \mathbf{A}' \mathbf{P} \boldsymbol{\xi}) \\ &+ (i' \mathbf{B}' \mathbf{P} \mathbf{A} \mathbf{X} + i' \mathbf{B}' \mathbf{P} \mathbf{B} i + i' \mathbf{B}' \mathbf{P} \mathbf{J} + i' \mathbf{B}' \mathbf{P} \boldsymbol{\xi}) \\ &+ (\mathbf{J}' \mathbf{P} \mathbf{A} \mathbf{X} + \mathbf{J}' \mathbf{P} \mathbf{B} i + \mathbf{J}' \mathbf{P} \mathbf{J} + \mathbf{J}' \mathbf{P} \boldsymbol{\xi}) \\ &+ (\boldsymbol{\xi}' \mathbf{P} \mathbf{A} \mathbf{X} + \boldsymbol{\xi}' \mathbf{P} \mathbf{B} i + \boldsymbol{\xi}' \mathbf{P} \mathbf{J} + \boldsymbol{\xi}' \mathbf{P} \boldsymbol{\xi}) \\ &+ 2(\mathbf{X}' \mathbf{A}' \mathbf{W} + i' \mathbf{B}' \boldsymbol{\omega} + \mathbf{J}' \boldsymbol{\omega} + \boldsymbol{\xi}' \boldsymbol{\omega}) \end{aligned} \right] + \delta d \end{aligned} \right\}. \quad (4.21)$$

The expected value of stochastic shocks is zero so terms of the form $\mathbf{X}' \mathbf{A}' \mathbf{P} \boldsymbol{\xi}$, $i' \mathbf{B}' \mathbf{P} \boldsymbol{\xi}$, $\mathbf{J}' \mathbf{P} \boldsymbol{\xi}$, $\boldsymbol{\xi}' \mathbf{P} \mathbf{A} \mathbf{X}$, $\boldsymbol{\xi}' \mathbf{P} \mathbf{B} i$, $\boldsymbol{\xi}' \mathbf{P} \mathbf{J}$, $\boldsymbol{\xi}' \mathbf{P} \boldsymbol{\xi}$ and $\boldsymbol{\xi}' \boldsymbol{\omega}$ drop out. We are left with:

$$V(\mathbf{X}) = \min_{\{i\}} \left\{ \begin{aligned} & (\mathbf{X} - \mathbf{X}^*)' \mathbf{R} (\mathbf{X} - \mathbf{X}^*) \\ & + \delta E \left[\begin{aligned} & (\mathbf{X}' \mathbf{A}' \mathbf{P} \mathbf{A} \mathbf{X} + \mathbf{X}' \mathbf{A}' \mathbf{P} \mathbf{B} i + \mathbf{X}' \mathbf{A}' \mathbf{P} \mathbf{J}) \\ & + (i' \mathbf{B}' \mathbf{P} \mathbf{A} \mathbf{X} + i' \mathbf{B}' \mathbf{P} \mathbf{B} i + i' \mathbf{B}' \mathbf{P} \mathbf{J}) \\ & + (\mathbf{J}' \mathbf{P} \mathbf{A} \mathbf{X} + \mathbf{J}' \mathbf{P} \mathbf{B} i + \mathbf{J}' \mathbf{P} \mathbf{J}) \\ & + 2(\mathbf{X}' \mathbf{A}' \omega + i' \mathbf{B}' \omega + \mathbf{J}' \omega) \end{aligned} \right] \\ & + \delta d \end{aligned} \right\}, \quad (4.22)$$

which gives the necessary first-order condition for the minimisation problem with respect to i as⁸⁸:

$$\frac{\partial V(\mathbf{X})}{\partial i} = 2\delta [\mathbf{B}' \mathbf{P} \mathbf{A} \mathbf{X} + \mathbf{B}' \mathbf{P} \mathbf{J} + \mathbf{B}' \mathbf{P} \mathbf{B} i + \mathbf{B}' \omega] = 0. \quad (4.23)$$

Solving the above equation in terms of i yields the following policy reaction function:

$$i^a = -(\mathbf{B}' \mathbf{P} \mathbf{B})^{-1} (\mathbf{B}' \mathbf{P} \mathbf{A} \mathbf{X} + \mathbf{B}' \mathbf{P} \mathbf{J} + \mathbf{B}' \omega), \quad (4.24)$$

which implies that the solution to this problem under additive uncertainty is a linear function of the state variable \mathbf{X} .

More succinctly, we have:

$$i^a = \mathbf{F} \mathbf{X} + \mathbf{Z} \quad (4.25)$$

where the matrix $\mathbf{F} = -(\mathbf{B}' \mathbf{P} \mathbf{B})^{-1} \mathbf{B}' \mathbf{P} \mathbf{A}$, and $\mathbf{Z} = -(\mathbf{B}' \mathbf{P} \mathbf{B})^{-1} [\mathbf{B}' \mathbf{P} \mathbf{J} + \mathbf{B}' \omega]$. Economically, this policy reaction function is independent of the stochastic shocks ξ_t .

Substituting the optimal policy rule (4.25) back into the right side of Equation (4.20), we obtain:

⁸⁸ Use the rules $\partial \mathbf{x}' \mathbf{A} \mathbf{x} / \partial \mathbf{x} = 2 \mathbf{A} \mathbf{x}$, $\partial \mathbf{y}' \mathbf{B} \mathbf{z} / \partial \mathbf{y} = \mathbf{B} \mathbf{z}$, $\partial \mathbf{y}' \mathbf{B} \mathbf{z} / \partial \mathbf{z} = \mathbf{B}' \mathbf{y}$, and note also the fact that \mathbf{P} is a symmetric matrix. See, for example, Ljungqvist and Sargent (2000).

$$\begin{aligned}
& \mathbf{X}'\mathbf{P}\mathbf{X} + 2\mathbf{X}'\boldsymbol{\omega} + d \\
& = \min_{\{i\}} \left\{ \begin{aligned} & (\mathbf{X} - \mathbf{X}^*)' \mathbf{R} (\mathbf{X} - \mathbf{X}^*) \\ & + \delta E \left(\begin{aligned} & [\mathbf{A}\mathbf{X} + \mathbf{B}(\mathbf{F}\mathbf{X} + \mathbf{Z}) + \mathbf{J}]' \mathbf{P} [\mathbf{A}\mathbf{X} + \mathbf{B}(\mathbf{F}\mathbf{X} + \mathbf{Z}) + \mathbf{J}] \\ & + 2[\mathbf{A}\mathbf{X} + \mathbf{B}(\mathbf{F}\mathbf{X} + \mathbf{Z}) + \mathbf{J}]' \boldsymbol{\omega} \end{aligned} \right) + \delta d \end{aligned} \right\}. \quad (4.26)
\end{aligned}$$

Rearranging Equation (4.26), thus the matrix \mathbf{P} is determined by the following equation:

$$\mathbf{P} = \mathbf{R} + \delta \mathbf{A}' \mathbf{P} \mathbf{A} - \delta \mathbf{A}' \mathbf{P} \mathbf{B} (\mathbf{B}' \mathbf{P} \mathbf{B})^{-1} \mathbf{B}' \mathbf{P} \mathbf{A}. \quad (4.27)$$

And the vector $\boldsymbol{\omega}$ satisfies:

$$\boldsymbol{\omega} = [\mathbf{I} - \delta \mathbf{A}' (\mathbf{I} - \mathbf{P} \mathbf{B} (\mathbf{B}' \mathbf{P} \mathbf{B})^{-1} \mathbf{B}')]^{-1} [\mathbf{R} \mathbf{X}^* + \delta \mathbf{A}' \mathbf{P} (\mathbf{I} - \mathbf{B} (\mathbf{B}' \mathbf{P} \mathbf{B})^{-1} \mathbf{B}' \mathbf{P}) \mathbf{J}]. \quad (4.28)$$

Equation (4.25) illustrates the well-known result that in a linear-quadratic framework the optimal feedback rule is linear in the state variables. The feedback parameters can be obtained from (4.25) by iterating on Equation (4.27). Moreover, Equation (4.25) implies that the optimal policy rate is a function of all current and lagged values of the non-policy variables and lagged values of the policy rates. In this regard, the derived optimal policy rule here is less restrictive than the Taylor-type rules in which the policy rates are commonly constructed to respond only to the current inflation deviations from its target and the output gap, or the lagged interest rate which captures the interest-rate smoothing.

The optimal policy will not be affected by additive uncertainty – the certainty equivalence principle holds as the objective function is assumed to be a quadratic form.

4.2.2.3 Calculation of Optimal Policy Rules with Parameter Uncertainty.

In the economy where there is only additive uncertainty, the policy choices are assumed to be independent of the variances of target variables; accordingly, the optimal policy focuses solely on minimising squared deviations of expected target variables from their respective target levels. Contrary to the case of additive uncertainty, however, the optimal policy with parameter uncertainty considers the information given by the variance-covariance matrix of the estimated VAR coefficients. By using the variance-covariance matrix, we can measure the parameter uncertainty generating from estimates of the model. Under the assumption that the dynamic structure of the economy is invariant over the sample, we can analyse its effect on optimal policy.

In order to investigate the effect of parameter uncertainty on the optimal policy, we first show how parameter uncertainty has an impact on the state variables. Due to the complexity of the optimisation problem in the presence of uncertainty about the dynamic evolution of the state variable, we need to simplify the problem. To this end, Sack (2000) replaced the state variable vector X_t with the *predicted* values of the state variables given all information available at time $t - 1$, that is, $\hat{X}_t = E_{t-1}[X_t]$. This restriction implies that the central bank cannot respond to contemporaneous shocks to the non-policy variables. This assumption is probably adequate: when policymakers choose the key policy rate, they do not know the true values of the state variables, rather, they use forecasts.

Under this assumption, the path of the new state variable is identical to that in the case of only additive uncertainty, except replacing X_t with \hat{X}_t . That is, the law of motion will be given by Equation (4.29), repeated here for convenience:

$$\hat{\mathbf{X}}_{t+1} = \mathbf{A} \hat{\mathbf{X}}_t + \mathbf{B} i_t + \mathbf{J} + \xi_{t+1}, \quad (4.29)$$

where $\hat{\mathbf{X}}_t = E_{t-1}[\mathbf{X}_t]$. As in the additive case, the matrix \mathbf{A} , and the vectors \mathbf{B} and \mathbf{J} determine the path of the expected state variable vector, consisting of the point estimates obtained from the VAR model estimation.

As in the simple case under parameter uncertainty discussed in Subsection 4.2.1, the per-period loss function is affected both by the squared deviations of expected state variables from their targets and by the conditional variances of targeted variables.⁸⁹ This is because, in the presence of parameter uncertainty, the variances of target variables will affect the policy choice. Therefore, the solution to the optimisation problem faced by the central bank satisfies the following Bellman equation:

$$V(\hat{\mathbf{X}}_t) = \min_{\{i_t\}} \frac{1}{2} \left\{ (\hat{\mathbf{X}}_t - \mathbf{X}^*)' \mathbf{R} (\hat{\mathbf{X}}_t - \mathbf{X}^*) + (\hat{\mathbf{X}}_t' \mathbf{M} \hat{\mathbf{X}}_t + 2 \hat{\mathbf{X}}_t' \mathbf{N}) + \delta E_t[V(\hat{\mathbf{X}}_{t+1})] \right\}, \quad (4.30)$$

subject to $\hat{\mathbf{X}}_{t+1} = \mathbf{A} \hat{\mathbf{X}}_t + \mathbf{B} i_t + \mathbf{J} + \xi_{t+1}.$

It is important to note that the above loss function is decomposed into two terms: the first term, $(\hat{\mathbf{X}}_t - \mathbf{X}^*)' \mathbf{R} (\hat{\mathbf{X}}_t - \mathbf{X}^*)$ is the weighted sum of the squared values of the expected deviations of the state variables from the targets; and the second term, $(\hat{\mathbf{X}}_t' \mathbf{M} \hat{\mathbf{X}}_t + 2 \hat{\mathbf{X}}_t' \mathbf{N})$ is the weighted sum of the conditional variance of the targeted variables. This second term captures the effect of parameter uncertainty, accounting for the variances of the targeted variables arising from the setting of the central bank's policy rate. The matrix

⁸⁹ Using inflation as an example, we know that $E[(\pi_t - \pi^*)^2] = \text{Var}(\pi_t) + (\bar{\pi} - \pi^*)^2$, where $\bar{\pi}$ is the expected inflation and the variance is conditional on the information available at time t .

\mathbf{M} is defined as $\lambda \Sigma_y + 1 \Sigma_\pi$, where $(\lambda, 1)$ is the weight that the central bank places on the goal variables in the policy objective function, and Σ_y denotes the variance-covariance matrix of the coefficients on the state variable in the output gap equation. And, the matrix \mathbf{N} is the weighted sum of covariance vector of the state variables with the estimated constant in each equation.

As seen in Equation (4.25), the solution to this optimisation problem, seeking the optimal interest rate path (i_t^p) in the presence of parameter uncertainty is given by a linear function of the new state variable ($\hat{\mathbf{X}}_t$), such that:

$$i_t^p = -(\mathbf{B}'\mathbf{P}\mathbf{B})^{-1}(\mathbf{B}'\mathbf{P}\mathbf{A}\hat{\mathbf{X}}_t + \mathbf{B}'\mathbf{P}\mathbf{J} + \mathbf{B}'\omega). \quad (4.31)$$

where

$$\mathbf{P} = \mathbf{R} - \mathbf{M} + \delta \mathbf{A}'\mathbf{P}\mathbf{A} - \delta \mathbf{A}'\mathbf{P}\mathbf{B}(\mathbf{B}'\mathbf{P}\mathbf{B})^{-1}\mathbf{B}'\mathbf{P}\mathbf{A} \quad (4.32)$$

and

$$\omega = [\mathbf{I} - \delta \mathbf{A}'(\mathbf{I} - \mathbf{P}\mathbf{B}(\mathbf{B}'\mathbf{P}\mathbf{B})^{-1}\mathbf{B}')^{-1}][\mathbf{R}\mathbf{X}^* - \mathbf{N} + \delta \mathbf{A}'\mathbf{P}(\mathbf{I} - \mathbf{B}(\mathbf{B}'\mathbf{P}\mathbf{B})^{-1}\mathbf{B}'\mathbf{P})\mathbf{J}]. \quad (4.33)$$

The optimal policy under parameter uncertainty takes the same form of the path (i_t^a) under additive uncertainty. However, the presence of the matrices \mathbf{M} in Equation (4.32) and \mathbf{N} in Equation (4.33) highlights the difference in the two problems. Both matrices now depend on both estimates from the VAR and the variance-covariance matrices of the estimated coefficients from Equation (4.15).

4.3 Data and Some Empirical Issues

4.3.1 Data

In this chapter, quarterly data for Korea are used. The choice of this frequency rather than the monthly one does not reduce the study relevance, under the condition that the Bank of Korea attempts to attain a medium-term objective of price stability⁹⁰, and output data is compiled on a quarterly basis. The data is collected from the BOK database (ECOS) for the second quarter of 1999 to the fourth quarter of 2011. In fact, an inflation targeting policy in Korea started in April 1998. Nevertheless, the reason we use data from the second quarter of 1999 is that in Korea a specific figure for the overnight noncollateralised call rate, an equivalent of the US Federal Funds rate, began to be used as a target from May 1999 onwards.⁹¹

Three macroeconomic variables, the inflation rate gap, the output (real GDP) gap and policy interest rates, are analysed in this chapter. The first two variables are included as non-policy variables in the VAR. Both variables are represented as deviations of actual values from their desired levels. More specifically, the inflation gap is measured by $(\pi_t - \pi^T)$, where π_t is the CPI inflation rate, compared with the same period of the previous year, as a percentage, and π^T is the target for annual inflation rate. The inflation target is announced by the Bank of Korea at the beginning of every three year period, so that they can be time-varying rather than fixed as assumed in the theoretical literature. The output gap, y_t , is defined as the percentage deviations of the level of real GDP (seasonally adjusted) from its potential level,

⁹⁰ In the medium-term objective horizon, sufficient flexibility for monetary policy can be allowed to take into account stabilisation of short-run economic fluctuations, leading to temporary deviations of inflation from the target. Therefore, central banks normally do not adjust interest rates every month. In this regard, quarterly data can be used to analyse the actual conduct of monetary policy.

⁹¹ Hitherto, without announcement of any specific figures, a vague expression such as “the downward stability of the call rate is to be induced” had normally been employed.

calculated by multiplying 100 times the natural logarithm of the ratio of real GDP to potential real GDP. The potential GDP is, as in other studies, assumed to be determined by the HP filtering method⁹². Before we applied the HP-filter, the sample period was extended with ARIMA-based forecasts of the real GDP series (Kaiser and Maravall, 1999), to take the end-of-sample problem into consideration⁹³. And the target output gap, y^T , was set to zero over the whole sample period. Finally, for the last variable, *i.e.*, policy interest rates, we chose to use the detrended interest rates⁹⁴. Detrending the call rate data is made by using the HP filtering method.

As in much literature, the central bank's loss function (4.16) mentioned above can be expressed as:

$$L = \min_{\{i_t\}} \frac{1}{2} E_t \left\{ \sum_{k=1}^{\infty} \delta^k [(\pi_{t+k} - \pi^T)^2 + \lambda(y_{t+k} - y^T)^2] \right\}. \quad (4.34)$$

The inclusion of the output gap variable, along with the inflation gap in the loss function, is based on the grounds that *output stability* is widely regarded as an important goal of the central bank together with *price stability*. The central bank's discount factor δ , in line with other researchers (for example, Söderström (2000)), is

⁹² For the measurement of potential output, the filtering method of Hodrick-Prescott (HP) is often used. HP filtering is a good estimation method since it minimises the output fluctuation around its trend. For quarterly data such as real GDP, the choice for lambda (λ), which means the value of smoothing parameter, is normally 1600.

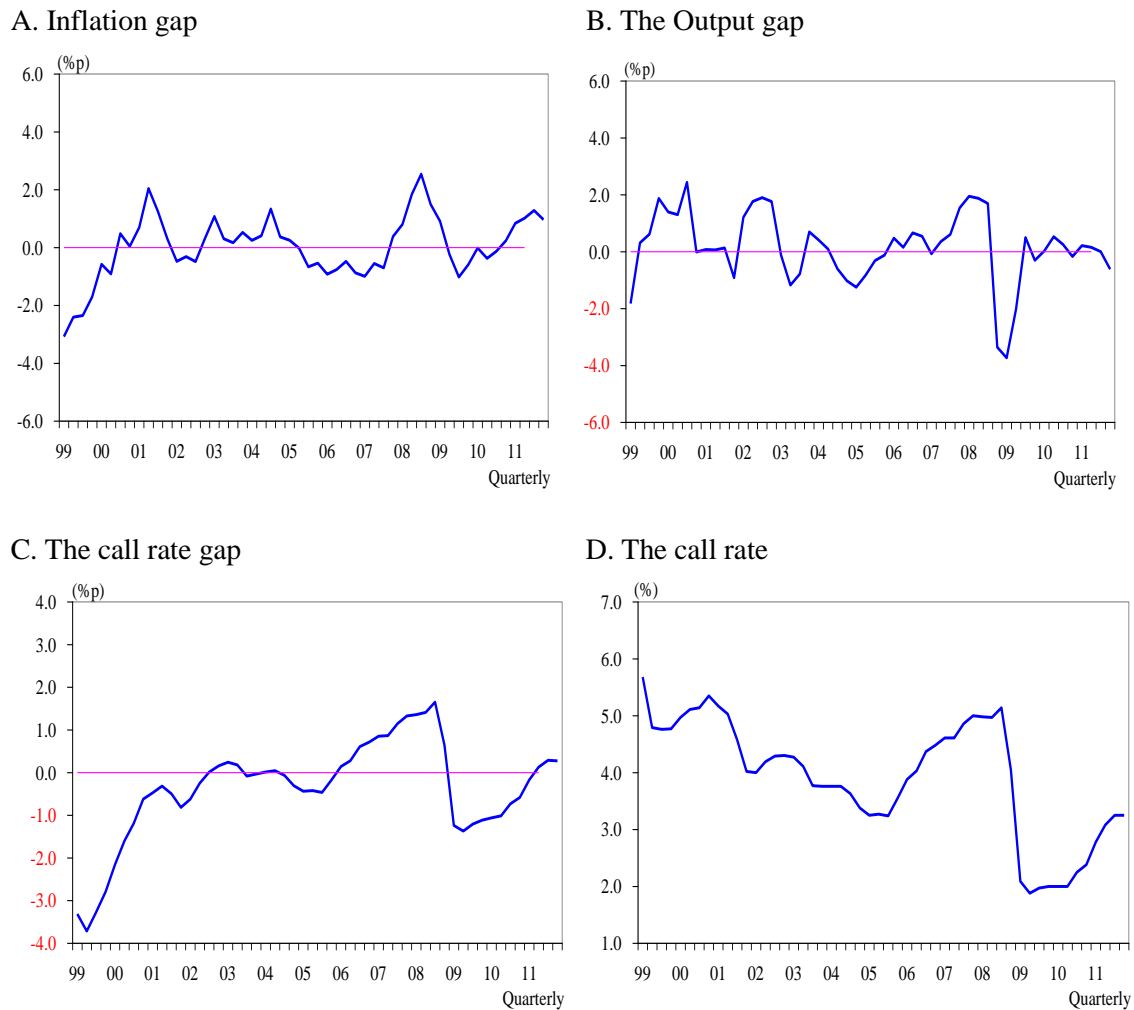
⁹³ It is quite easy to use an HP-filter to estimate the potential GDP. But, there are, in fact, several drawbacks in using this filter: it is completely mechanistic, *i.e.*, it has no explicit foundation in any economic theory; and a long lasting positive (or negative) output gap is ruled out a priori by the HP-filter. Moreover, there is an end-of-sample problem when a HP-filter is applied to estimate a potential GDP. See Chagny and Döpke (2001) for more explanation.

⁹⁴ Entering interest rates as deviations from their trend in the model means that the neutral rate is defined as the trend in nominal rates. Therefore, when objectives equal target values, the nominal interest rate should be set to their neutral level. See, Martin and Salmon (1999) for more explanation.

set to 0.987 per quarter, which implies a quarterly discount rate of around 1 percent.

Panels A to C in Figure 4.1 plot three data series that enter the VAR model and the loss function, and Panel D depicts the nominal policy interest rate.

Figure 4.1: Plots of Variables, 1999:q2–2011:q4



4.3.2 Unit Root Test and Lag Selection

Since all the variables, which enter the VAR, are defined as the gaps between the actual values and their respective targets, they appear to be stationary time-series.

Augmented Dickey-Fuller (ADF) and standard Phillips-Perron (PP) tests, which both have the null hypotheses of nonstationarity (a unit root), are employed in order to test the stationarity of these variables. The test statistics in Table 4.1 clearly indicate the rejection of the null-unit root hypothesis at the usual levels of significance. We obtain similar results from the KPSS test, which has a null hypothesis of stationarity, so that we do not report the KPSS test result. We find the output gap and inflation gap, and interest rate gap to be $I(0)$ processes at the 1 percent and 5 percent significance level, respectively, which imply that they are stationary series

Table 4.1: Unit Root Tests, 1999:q2–2011:q4

	ADF t-statistic		PP t-statistic	
	$H_0 : I(0)$	$H_0 : I(1)$	$H_0 : I(0)$	$H_0 : I(1)$
Output gap	-4.49 **	—	-3.95 **	—
Inflation gap	-3.59 **	—	-2.98 *	-9.46 **
Interest rate gap	-4.18 **	—	-4.50 **	—
Call rate	-2.66 [†]	-4.85 **	-2.00	-4.84 **

Notes: 1. The superscripts **, * and [†] indicate rejection of the null-unit root hypothesis (H_0) at 1%, 5% and 10% levels of significance, respectively.

2. An intercept term is included in the ADF and PP regressions for the unit root tests. When an intercept term is only included, Mackinnon critical values for the ADF and PP tests are -3.57, -2.92 and -2.60 at the 1%, 5% and 10%, respectively.

And, two lag lengths of each variable in the VAR model are chosen following the Akaike information criterion (AIC) which is generally known to be less conservative in terms of lag length than the Schwarz criterion (SC) — the results of which are presented in Table 4.2. This is because such lag lengths allow the VAR model to reflect a sufficiently rich dynamic structure generated by the implementation of monetary policy.

Table 4.2: VAR Lag Order Selection Criteria

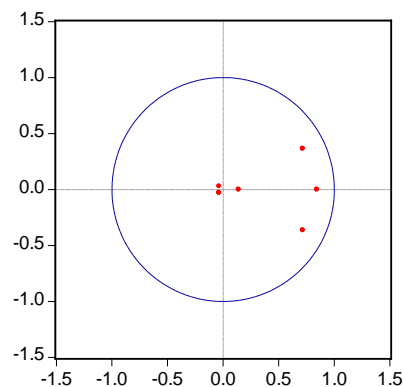
Lags	Schwarz criterion (SC)	Akaike information criterion (AIC)
0	9.41	9.29
1	4.86*	4.40
2	5.20	4.39*
3	5.72	4.57
4	6.08	4.58
5	6.51	4.65

Note: The superscripts * indicate a lag order selected by each criterion.

The inverse roots of the characteristic polynomial as in Lütkepohl (1991) are reported in Table 4.3 and Figure 4.2. None of the root values lie outside the unit circle, which implies that the VAR model satisfies the stability condition.

Table 4.3: Roots of Characteristic Polynomial

Root	Modulus
0.843781	0.843781
0.717127 - 0.364823i	0.804591
0.717127 + 0.364823i	0.804591
0.139938	0.139938
-0.036462 - 0.028908i	0.046531
-0.036462 + 0.028908i	0.046531

Figure 4.2: Inverse Roots of AR Characteristic Polynomial

Note: No root lies outside the unit circle.

As reported in Table 4.4 for the output gap equation, the test statistic shows the rejection of the null hypothesis of normality at the 1% significance level. The normality assumption is violated in the output gap equation. However, as Hamilton (1994, p.298) notes, even if the innovations are non-normal, OLS estimators of population parameters are consistent. Therefore, this should not pose a serious problem in our analysis.

Table 4.4: Test Results for Normality

Component	Jarque-Bera statistic	d.f.	Prob.
Output gap equation	23.9850	2	0.0000***
Inflation gap equation	1.74885	2	0.4171
Policy interest rate equation	1.62892	2	0.4429
Joint	27.3628	6	0.0001***

Note: The superscript *** indicates rejection of the null hypothesis (H_0) at the 1% level of significance. The null hypothesis of normal distribution is that residuals are multivariate normal. The Jarque-Bera statistic asymptotically follows the chi-squared(χ^2) distribution. Its critical value is 9.21 at the 1% significance level.

4.3.3 VAR Model Identification

In contrast to Sack (2000)⁹⁵, we employed a structural VAR (SVAR) to estimate the policy reaction rules. For impulse response analysis, this approach applies non-recursive restrictions to the contemporaneous relationships among the economic variables.

In general, the SVAR model with two lags and three variables can be expressed as the state-space representation, which can be written as:

$$B_0 Y_t = C + \Gamma_1 Y_{t-1} + \Gamma_2 Y_{t-2} + D\mu_t, \quad (4.35)$$

⁹⁵ Sack's method used the unrestricted VAR model, which decomposes the variance-covariance matrix of residuals into its lower triangular square root for identification of the VAR equation. This decomposition is called a triangularisation, which is also known as a Choleski decomposition. This imposes a recursive response to the disturbances (See Sims (1980)).

where vectors of endogenous variables Y_t , Y_{t-1} and Y_{t-2} , a constant term vector C , coefficient matrices B_0 , Γ_1 , Γ_2 and D , and a vector of disturbances (or pure innovations) μ_t are given by:

$$B_0 = \begin{bmatrix} b_{11} & b_{12} & b_{13} \\ b_{21} & b_{22} & b_{23} \\ b_{31} & b_{32} & b_{33} \end{bmatrix}, Y_t = \begin{bmatrix} y_t \\ \pi_t \\ i_t \end{bmatrix}, C = \begin{bmatrix} c_y \\ c_\pi \\ c_i \end{bmatrix}, \Gamma_1 = \begin{bmatrix} r_1^{11} & r_1^{12} & r_1^{13} \\ r_1^{21} & r_1^{22} & r_1^{23} \\ r_1^{31} & r_1^{32} & r_1^{33} \end{bmatrix}, \Gamma_2 = \begin{bmatrix} r_2^{11} & r_2^{12} & r_2^{13} \\ r_2^{21} & r_2^{22} & r_2^{23} \\ r_2^{31} & r_2^{32} & r_2^{33} \end{bmatrix},$$

$$Y_{t-1} = \begin{bmatrix} y_{t-1} \\ \pi_{t-1} \\ i_{t-1} \end{bmatrix}, Y_{t-2} = \begin{bmatrix} y_{t-2} \\ \pi_{t-2} \\ i_{t-2} \end{bmatrix}, D = \begin{bmatrix} d_{11} & 0 & 0 \\ 0 & d_{22} & 0 \\ 0 & 0 & d_{33} \end{bmatrix}, \text{ and } \mu_t = \begin{bmatrix} \mu_{yt} \\ \mu_{\pi t} \\ \mu_{it} \end{bmatrix}.$$

Equation (4.35) represents a VAR in *primitive* form. Premultiplication by B_0^{-1} allows us to obtain the VAR model in a *standard* form, *i.e.*, a reduced form of equation so that:

$$Y_t = \Phi_0 + \Phi_1 Y_{t-1} + \Phi_2 Y_{t-2} + e_t. \quad (4.36)$$

where, $\Phi_0 = B_0^{-1}C$, $\Phi_1 = B_0^{-1}\Gamma_1$, $\Phi_2 = B_0^{-1}\Gamma_2$, and $e_t = B_0^{-1}D\mu_t$.

Given estimates of the regression residuals (e_t) of an n -equation VAR in reduced form, a necessary condition for the identification of the structural innovations (μ_t) in the primitive form can be obtained by imposing $(n^2-n)/2$ restrictions on the B_0^{-1} matrix (Enders, 2004), p.323). We can easily verify that a Choleski decomposition which requires all elements above the principal diagonal to be zero, always results in an exactly identified system. However, the ordering used in the Choleski decomposition may not be in accord with economic theory. Bernanke (1986) and Sims (1986) developed a procedure that allows one to impose $(n^2-n)/2$ or more restrictions on the structural model.

If more than $(n^2-n)/2$ restrictions are imposed, the system is overidentified and the overidentifying restrictions need to be tested. According to the Sims-Bernanke decomposition, we need to indicate the pattern of the \mathbf{B}_0^{-1} matrix. Using the notation from Equation (4.35), the relationship between the regression residuals, \mathbf{e}_t and the pure shocks (*i.e.*, the structural innovations), $\boldsymbol{\mu}_t$ is given by:

$$\mathbf{e}_t = \mathbf{B}_0^{-1} \boldsymbol{\mu}_t \quad (4.37)$$

which implies that we can estimate the random stochastic residual $\mathbf{B}_0^{-1} \boldsymbol{\mu}_t$ from the regression residuals \mathbf{e}_t of the estimated unrestricted VAR. Here, notice that \mathbf{D} in the equation $\mathbf{e}_t = \mathbf{B}_0^{-1} \mathbf{D} \boldsymbol{\mu}_t$ is a (3×3) matrix that consists of *ones* on the principal diagonal elements and *zeros* off the diagonal.

In this section, the SVAR identification follows the method that applies non-recursive restrictions to the contemporaneous relationships among the variables (see Sims, 1986; Leeper *et al.*, 1996; and Martin and Salmon, 1999). Accordingly, the output gap y_t responds to all other shocks with a lag, and inflation π_t responds to within-period output gap shocks while it responds to interest rate shocks with a lag. Finally, the nominal interest rate i_t responds to output gap shocks with a lag, but to inflation shock within period.⁹⁶ Therefore, note that the ordering of the variables as $[y_t, \pi_t, i_t]$ in the VAR is such that interest rate responds contemporaneously to shocks in inflation gap and its own shocks. Inflation responds contemporaneously to shocks in the output gap and its own shocks. However, the output gap responds contemporaneously to its own shocks only.

⁹⁶ For identification of the VAR model, we can consider the method to decompose the variance-covariance matrix of residuals into its lower triangular square root (Sack, 2000) or Choleski factor following Sims (1980).

Under this identification scheme, by imposing a structure on matrix \mathbf{B}_0^{-1} in Equation (4.37), we can model contemporaneous relationships between the regression residuals and the pure innovations such that:

$$\begin{bmatrix} e_{y,t} \\ e_{\pi,t} \\ e_{i,t} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ b_{21} & 1 & 0 \\ 0 & b_{32} & 1 \end{bmatrix} \begin{bmatrix} \mu_{y,t} \\ \mu_{\pi,t} \\ \mu_{i,t} \end{bmatrix}$$

where the b_{jk} are the coefficients of \mathbf{B}_0^{-1} . The restrictions on a matrix \mathbf{B}_0^{-1} is a lower triangular matrix with ones on the main diagonal and with zero on the b_{31} . Notice that we have restricted four elements of \mathbf{B}_0^{-1} to be zero on the b_{jk} . In a three-variable system, since $(3^2 - 3)/2 = 3$, three restrictions need to be imposed if the structural model is to be identified exactly: hence, the system contains one overidentifying restriction.

4.3.4 The Policymaker's Preference Weights

The optimal policy rule, which is derived from the objective function subject to constraints, is affected by the relative weights that the central bank places on variables in the objective function. For instance, when the central bank places a high weight on the output gap movements, it would react more strongly to this. A grid search technique over the policy rule coefficients is widely employed to find various combinations of policy weights. The optimal policy rate can be calculated under each combination of weights. We can find the relative weights that minimise the mean squared error (MSE) between the actual interest rate and the optimal interest rate (Martin and Salmon, 2000).

For the Korean models, the weight on the inflation gap was normalised to 1, and then the weight on the output gap was calculated by the grid-search technique. As a result,

the weight on the output gap was found to be 0.4⁹⁷. These findings reflect the fact that the BOK takes price stability as the most important objective of its monetary policy, and also seeks to bring about output stability.⁹⁸

After all, it can be said that the BOK takes sustainable economic growth as well as price stability as its primary objectives. Of course, it is argued that after the revision of the Bank of Korea Act in 1998 that stipulates an inflation targeting in which price stability is regarded as the most important goal, the BOK's legal responsibility and direct roles in boosting economic growth might be weakened. But, it is also true that because the consistent restructuring in the financial and corporate sector has led to the economic instability, the BOK has also placed stress on economic growth or real economic stability in the practical conduct of policy. To sum up, the weight on the output gap, 0.4 is satisfied with $0 < \lambda < 1$, meaning that the BOK responds to output, but it does less than inflation.

4.4 Empirical Results

4.4.1 Optimal Policy Rule under Parameter Uncertainty

Before proceeding, it is worth performing the VAR lagrange multiplier (LM) test which is used to check for serial correlation in the residuals of the estimated VAR. The LM test did not reject the null hypothesis of no serial correlation up to lag order 2: this result clearly implies that the VAR models employed in this chapter are specified fairly well (F

⁹⁷ This weight is a bit smaller than the value found by Chang and Lim (2011) who obtained a weight of 0.5 for the industrial production gap instead of the GDP gap.

⁹⁸ Before the revision of the Bank of Korea Act in 1998, the BOK's policy objective was to achieve price stability and economic development and the efficient usage of national resources.

statistic = 8.47 with a p -value = 0.49; F statistic = 9.34 with a p -value = 0.41).⁹⁹

Therefore, it can be said that the measure of parameter uncertainty represented by the variance-covariance matrix of the VAR is suitable for carrying out our analysis.

Panel A and Panel B in Figure 4.3 plot the values of the optimal call rates under *additive* and *parameter* uncertainties, respectively, given the true state of the economy in each quarter. In both cases, the optimal policy rule responds more vigorously to changes in the state of the economy than the actual policy rule does. As a result, the Korean call rate is more volatile under the optimal policy rule than that under the observed policy rule.

Panel A displays the optimal interest rate path, obtained by Equation (4.24) under only additive uncertainty. As shown in Panel A, the central bank can take immediate measures in order to offset the deviations of economic variables by moving the interest rate aggressively. In the economy where there is only additive uncertainty, this type of uncertainty does not have an influence on policy decision-making processes since the certainty equivalence principle (CEP) holds. Therefore, when taking the policy-decisions, the central bank does not need to care about future shocks (uncertainty). This implies that if there is a high possibility of deviations from the policy targets, the central bank having the incentive to adjust macroeconomic variables around their targets can just respond to those deviations as quickly as possible. Hence, the optimal monetary policy rule can be expected to move more aggressively than the actual policy rule.

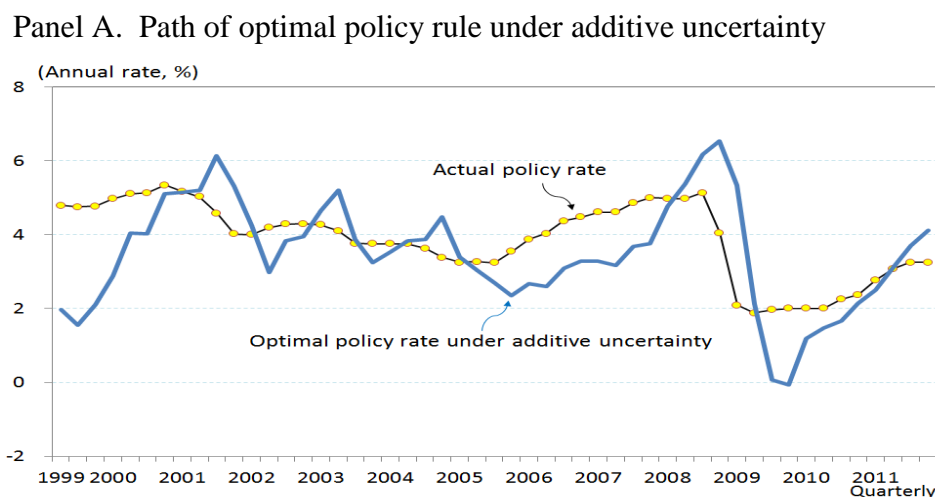
In reality, monetary policymakers always face a wide range of uncertainties when choosing policy at each period of time. In this context, it is unrealistic to imagine the

⁹⁹ Under the null hypothesis of no serial correlation of lag order, the LM statistic is asymptotically distributed χ^2 with k^2 degrees of freedom. See Johansen (1995, p.22) for the formula of the LM statistic.

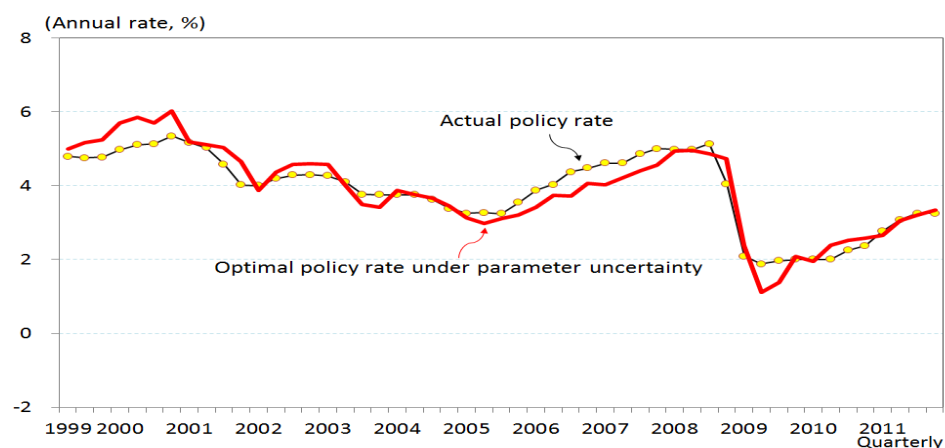
economy where policymakers can ignore uncertainty. After all, as plotted in Panel A in Figure 4.3, a large difference between the actual policy rule and the optimal rule under additive uncertainty comes from the unrealistic assumption that there exists only additive uncertainty in the monetary policy environment. It is important to note that Panel A just witnesses that the analysis of policy rules under additive uncertainty might ignore an important element, that is, parameter uncertainty when conducting monetary policy.

Turning to Panel B in Figure 4.3, it depicts the optimal interest rate path obtained by Equation (4.30) under parameter uncertainty. The optimal policy rule is a path for policy rates under parameter uncertainty. Although there are still some differences, the red, solid line of optimal policy rule is much closer to the actual policy rates followed throughout one and a half decades than that under additive uncertainty seen in Panel A. Based on this evidence, it can be said that the optimal policy interest rule in the presence of parameter uncertainty is much more successful in matching the actual level of the call money rate than when there is only additive uncertainty over the sample period.

Figure 4.3: Actual Policy Rule and Optimal Policy Rule under Uncertainty
(1999:q2 to 2011:q4)



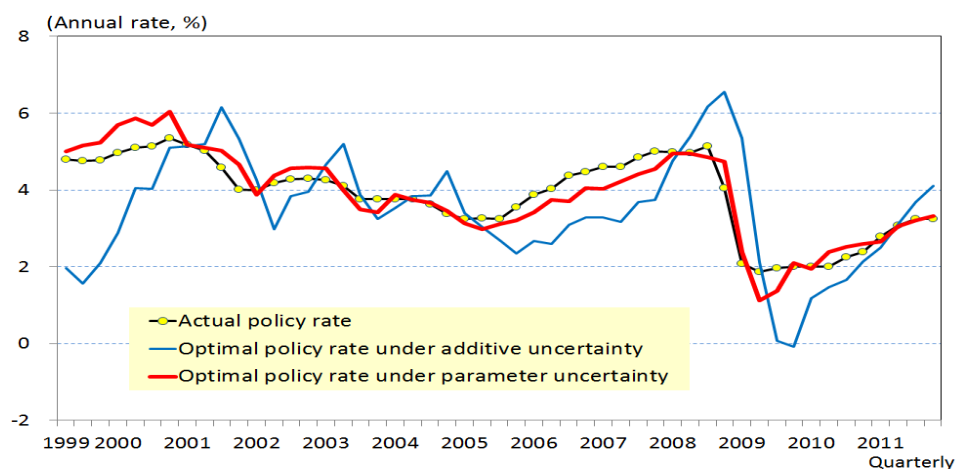
Panel B. Path of optimal policy rule under parameter uncertainty



Note: Actual policy rule is the path of the overnight call rate.

For convenient comparison, Figure 4.4 draws three superimposed interest rate paths. We can easily see that the optimal rate path assuming solely additive uncertainty is greatly jagged, displaying more reversals of direction than the case under parameter uncertainty. It is also evident that the optimal interest rate path under parameter uncertainty is much closer to the actual interest rate movements than to that under only additive uncertainty. In other words, the optimal policy rule under parameter uncertainty explains more effectively the actual behaviour of the policy rate than when only additive uncertainty is considered.

Figure 4.4: Paths of Interest Rate under Additive and Parameter Uncertainty



From Figure 4.4, we can assess the actual monetary policy conducted by the BOK in Korea. As is evident, the prescriptions of the optimal policy rule under parameter uncertainty follow the broad contour of the actual policy interest rate but the optimal rule sometimes lie above or below the actual rate over the entire period. However, from the second quarter of 2005 to the first quarter of 2008, the difference between the optimal policy rule prescriptions under parameter uncertainty and the actual policy rate showed to persist longer: the former prescriptions lie below the latter for about twelve quarters. This finding means that monetary policy was markedly too tight during that period. On average, the actual policy rate is about 25 bps above the optimal rule prescriptions. However, starting in the second half of 2008, the actual policy rate followed the optimal rule prescriptions fairly well except for some periods, especially from the third quarter until the fourth quarter of 2009, during which the optimal policy rule indicated more accommodative monetary policy in order to respond to the global financial crisis.

Table 4.5 presents the values of each mean, standard deviation and volatility for three policy rules over the sample period. It might be useful to compare the standard deviation and volatility for the optimal policy rule under parameter uncertainty with those under additive uncertainty. As can be seen, the former values are all smaller than the latter values, getting closer to those in the actual policy interest rate. These findings are consistent with the idea that policymakers in the face of uncertainty will prefer to move policy interest rates less aggressively in response to a shock.

Table 4.5: Comparisons of Standard Deviation and Volatility of Policy Rate under Uncertainty: The inflation targeting period, 1999:q2–2011:q4

■ Actual policy interest rate	Mean	3.885
	Standard deviation	1.016
	volatility	0.261
■ Optimal interest rate under additive uncertainty	Mean	3.501
	Standard deviation	1.458
	Volatility	0.416
■ Optimal interest rate under parameter uncertainty	Mean	3.904
	Standard deviation	1.155
	Volatility	0.296

Note: Volatility is measured by the ‘coefficient of variation’, *i.e.*, ‘the ratio of the standard deviation to the mean’.

4.4.2 A Difference of Policy Responses under Uncertainty

Aggressive movements of the call money rate become evident by comparing the impulse response functions of the two policies to various shocks in the economy. Following the identification assumptions on the VAR, which are non-recursive restrictions, the matrix (denoted as B_0^{-1}), describing the contemporaneous interaction of the variables with the ordering of the variables as $[y_t, \pi_t, i_t]$ in the VAR system, was estimated as:

$$\begin{array}{cc}
 < \text{Additive Uncertainty Case} > & < \text{Parameter Uncertainty Case} > \\
 B_0^{-1} = \begin{bmatrix} 1 & 0 & 0 \\ -0.10838 & 1 & 0 \\ 0 & -0.99974 & 1 \end{bmatrix} & B_0^{-1} = \begin{bmatrix} 1 & 0 & 0 \\ -0.10831 & 1 & 0 \\ 0 & -0.25025 & 1 \end{bmatrix}
 \end{array}$$

Table 4.6 reports the off-diagonal coefficient estimates (b_{21} and b_{32}) and their respective corresponding standard errors, and the likelihood ratio (LR) test of the restrictions. According to the LR test of the restrictions, the overidentifying restrictions

cannot be rejected, meaning that the restricted models for additive and parameter uncertainties can be accepted at conventional significance levels.

Table 4.6: Off-diagonal Coefficient Estimates and the Likelihood Ratio Test of the Restrictions

<Additive Uncertainty Case>				<Parameter Uncertainty Case>			
Coefficient Estimates for Structural Decomposition				Coefficient Estimates for Structural Decomposition			
Row	Col	Value	Std. Error	Row	Col	Value	Std. Error
2	1	-0.10838	0.07609	2	1	-0.10831	0.07595
3	2	-0.99974	0.00110	3	2	-0.25025	0.64948
LR Test of Overidentification				LR Test of Overidentification			
Chi-square(1) = 0.0376 Signif. Level=0.8463				Chi-square(1) = 0.3248 Signif. Level=0.5701			

Under this restriction, impulse response functions (IRFs) of the actual policy rate (or the “observed” policy rule) and the optimal policy rate to a shock to each of the three variables in the VAR are calculated. Here, notice that the IRFs of the actual policy rate are the ones from the simple VAR with no allowance for uncertainty. Figure 4.5 plots these results.

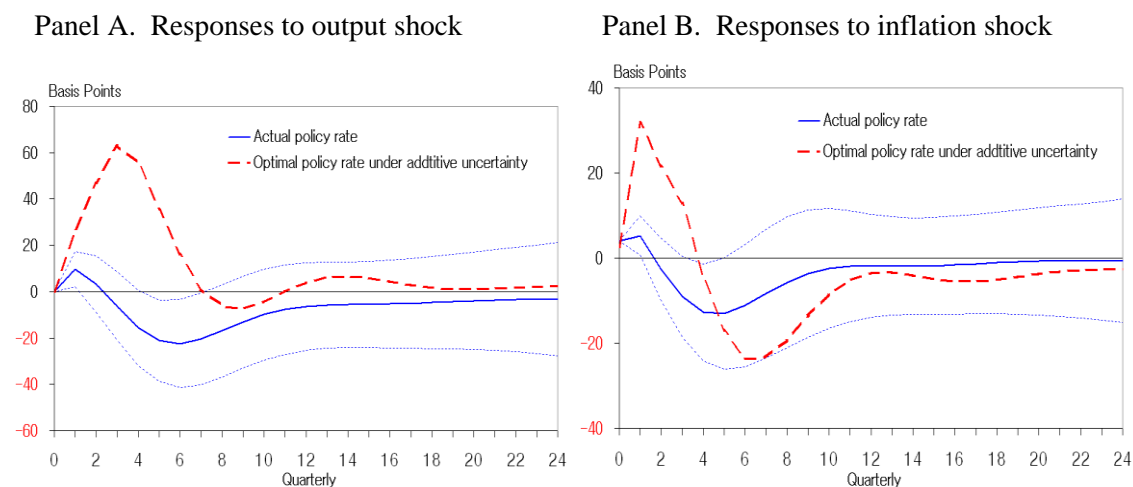
The IRFs of the actual policy rate to each of the three shocks in the economy imply the tendency for the central bank to conduct gradual and persistent adjustments in the policy rate. We found that the Bank of Korea chose to move the policy interest rate very gradually: it seems reluctant to respond to shocks aggressively. Moreover, the responses get back to initial levels very slowly, so that it takes more than three years to complete the whole response to a one-time shock. In response to a positive output gap shock, the policy rates rise. But this change occurs after the first quarter since it is assumed that output gap shocks have no contemporaneous effect on the policy rates in the VAR identification. The actual policy rate reverts to be negative from the third quarter while

the optimal policy rate remains positive for about six quarters.

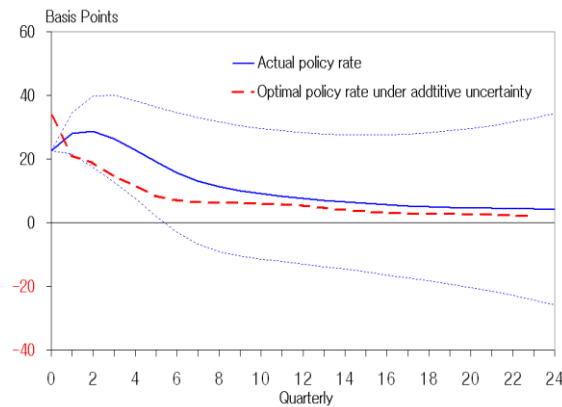
Notably, the extent of the response of the actual policy rate is smaller than that of the response of the optimal policy rate under additive uncertainty. This finding implies that the central bank tends to implement the monetary policy in a conservative manner.

Similar results are also found in the reaction of the policy rate to inflation shocks: the actual policy rate initially rises in response to a positive inflation shock, and from the second quarter the actual policy rate becomes negative, while from the fourth quarter the optimal policy rate under additive uncertainty becomes negative counter-intuitively. These negative responses build over many periods before slowly returning to their initial levels. However, the changes in the policy rates occur immediately following the inflation shocks. This is because we assume that policymakers respond immediately to the inflation shocks in the VAR identification. Likewise, the extent of changes in the actual policy rate is slightly smaller than that of the optimal policy rate derived from the additive uncertainty model.

Figure 4.5: Impulse Response Functions under Additive Uncertainty



Panel C. Responses to policy rate shock



Note: The solid lines are the impulse responses of actual policy interest rates to shocks of the output gap, the inflation gap and the policy interest rate, respectively. The dotted lines around the impulse responses mark two standard error bands (95% confidence intervals). The dashed red lines are the impulse responses of optimal policy rates under additive uncertainty to shocks of the output gap, the inflation gap and the policy interest rate, respectively.

These findings indicate that the optimal policy adjusts the interest rate more quickly than the observed policy and induces a much larger interest-rate response. Overall, there are substantial differences between the two policy rules. The additive uncertainty model fails to fully describe the gradual policy rate adjustments that are observed in the real policy practice. As can be seen in the figure above, the VAR model under additive uncertainty fails to explain the dynamic movements of the actual policy rate. Why? One of the possible explanations is that when we set up the model, we did not consider the interest-rate smoothing motive in the central bank's loss function. However, it is more plausibly rational that the model with only additive uncertainty cannot fully describe the real economy. Accordingly, it cannot reflect fully the problems the central bank may face (a misspecification problem). The analysis under additive uncertainty assumes that the structure of the economy is known with certainty, while the knowledge on disturbances with an additive form is not perfect. The policymaker normally does not know the real structure of the economy, but conducts policy on the basis of imprecisely estimated

values concerning the structure of the economy. As a consequence, the actual economic phenomenon cannot be explained by the simple model assuming solely additive uncertainty.

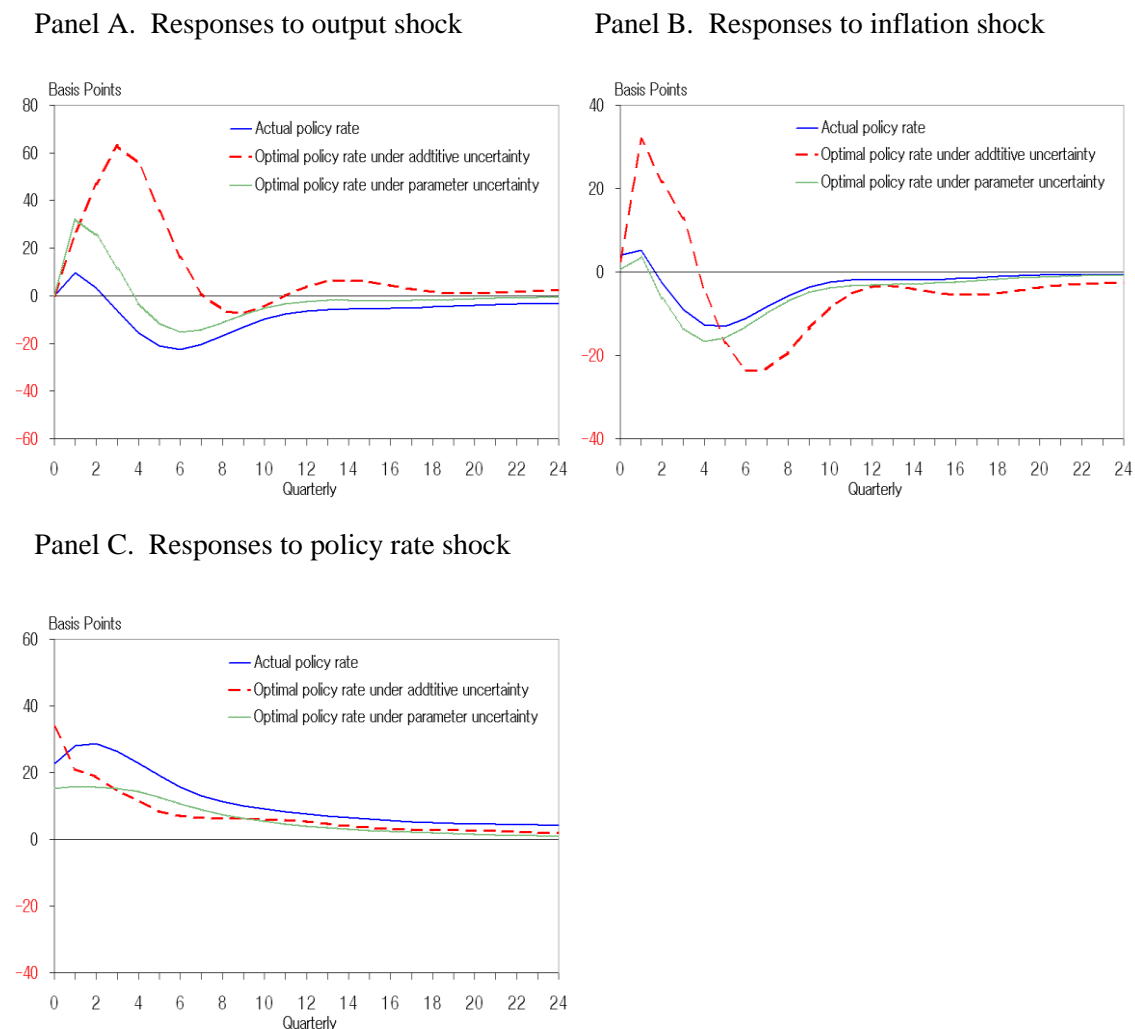
In a similar manner under only additive uncertainty, we calculated the impulse responses of the actual policy rate and the optimal policy rate under parameter uncertainty to three shocks identified in the VAR model. The behaviour of the optimal policy rate with parameter uncertainty is more successful in describing the actual policy rate movements. Figure 4.6 displays these results. It shows both the impulse response functions from the optimal policy rule assuming parameter uncertainty and those discussed in Figure 4.5 under additive uncertainty. Overall, the impulse responses of actual policy rate and the optimal policy rate under parameter uncertainty appear to be quite similar.

As seen in the IRFs below, parameter uncertainty reduces the volatility of policy interest rate, caused in response to macroeconomic variable shocks. For instance, once parameter uncertainty is considered, the optimal interest rate reaction to output gap shocks appears more drawn out than that under only additive uncertainty (Panel A in Figure 4.6). And, it is evident that the response of the optimal policy rate under parameter uncertainty is much closer to that of actual policy rate than to that under additive uncertainty. This evidence is consistent with the notion of conservatism in the conduct of monetary policy, *i.e.*, central banks move the policy interest rate less aggressively in response to shocks under parameter uncertainty.

In the case of the optimal policy rate response to inflation shocks, as seen in Panel B, similar results are found as well. Conservatism in the actual response is again apparent.

Notably, the response of the optimal policy rate with parameter uncertainty matches well with that of the actual policy rate. Its response becomes negative from the second quarter like that of actual policy rate, and remains negative for a long time contrary to our knowledge. It converges quite slowly to the equilibrium level. Of course, these movements in policy interest rates are the same as in the case where only additive uncertainty is considered.

Figure 4.6: Impulse Response Functions under Uncertainty



In terms of negative response, it is also found that the optimal policy rate under parameter uncertainty still reacts more aggressively than the actual policy rate. This means that the actual monetary policy is implemented in a timid way when compared with the monetary policy under parameter uncertainty.

In short, the optimal policy rate path accounting for parameter uncertainty is much closer to the actual policy rate path than to the optimal policy rate path under only additive uncertainty. This empirical evidence might imply that monetary policy in Korea has been conducted in consideration of the possibility of future (parameter) uncertainty. In other words, policymakers have not implemented the monetary policy in an aggressive fashion considering solely additive uncertainty, but they have instead given much attention to the possibility of occurrence of multiplicative uncertainty (say, parameter uncertainty) and thus conducting the monetary policy cautiously and gradually.

4.5 Conclusion

In this chapter, we have attempted to examine whether the parameter uncertainty matters in the conduct of monetary policy in Korea. To this end, we constructed a VAR model based on Sack (2000), and solved the dynamic programming problem in order to scrutinise the effect of uncertainty on monetary policy in Korea. And we calculated the impulse response functions based on the SVAR identification scheme. We focused on whether the gradual movements of policy rates can be explained by the parameter uncertainty that the central bank faces in choosing its policy instruments. As discussed in the literature review, it is found to be desirable for the central bank to operate its policy instruments gradually when there are considerable uncertainties.

We have found that parameter uncertainty might provide a possible explanation for a smoother path of the policy interest rate in Korea. In particular, since the introduction of an interest rate-oriented monetary policy in Korea, the actual policy rate has shown a similar movement to the optimal policy rate path under parameter uncertainty. Therefore, the analysis in this chapter might confirm that monetary policy in Korea has been conducted in a similar way to the optimal policy derived under the assumption that much uncertainty on parameters exist. In addition, it is found that gradual adjustment in the policy rates does not necessarily indicate that the central bank has an interest-rate smoothing incentive. Uncertainty and the dynamic structure of the economy can account for a considerable portion of the observed gradual movements of interest rates in Korea.

From the analysis, we obtained several implications of particular interest for monetary policy in Korea. First of all, it is found that there exists substantial difference between the actual (observed) policy interest rate and the optimal policy rate. In analysing monetary policy, when we consider exclusively additive uncertainty, it is nearly impossible to explain the actual behaviour of monetary policy conducted by the central bank. There are diverse types of uncertainty in the real economy, and consequently, ever-occurring shocks to the economy last for a considerable amount of time. Therefore, it is unrealistic to assume that the policymakers need no longer concern about future uncertainty.

The second implication is that the optimal policy rate path taking parameter uncertainty into account is even more similar to the actual policy rate path than to the optimal policy rate path under only additive uncertainty. This empirical evidence might imply that the central bank in Korea has conducted the monetary policy in consideration

of the possible existence of parameter uncertainty, which means that policymakers have implemented monetary policy in a cautious fashion having paid much attention to the possible occurrence of parameter uncertainty instead of having conducted the monetary policy in an aggressive manner considering only additive uncertainty.

Finally, the implication we obtained from the analysis is that there appears an interest-rate smoothing tendency in monetary policy in Korea owing to the consideration of parameter uncertainty. This evidence is the case with most major developed countries. Moreover, the optimal policy interest rate under parameter uncertainty is successful in explaining the actual interest rate movements. This means that even though there is no interest-rate smoothing motive in the central banks' objective function, when we assume that parameter uncertainty exists in the economy, central banks tend to behave as if they carry out interest-rate smoothing.

Chapter 5

Optimal Monetary Policy Rules under Data Uncertainty

5.1 Introduction

The availability of relevant data is one of the important issues in the implementation of monetary policy. In conventional econometric analysis, it is assumed that the relevant data are available to policymakers in real time. However, in reality, much macroeconomic data, for example on real output are only available with a considerable lag and are often subject to frequent and large revisions at a later date. Moreover, as discussed in Chapter 1, some key macroeconomic variables such as the output gap and equilibrium real interest rate are unobservable and must be estimated. Moreover, estimates of these differ considerably according to the estimation period, econometric methods and a sample size.¹⁰⁰ There is, therefore, likely to be substantial measurement

¹⁰⁰ Orphanides (2003) illustrates that mismeasurement in the output gap reflects two types of errors: errors in the measurement of actual and potential GDP. Main errors of the output gap are due to errors in measurement of potential output.

errors in both *actual* and *potential* output, leading to inaccurate estimates of the output gap. Similarly, the equilibrium level of real interest rate varies over time as it rests on a number of factors such as the growth rate of potential output and fiscal policy stance (Kohn, 2007).

In addition, there are various alternative measures of the inflation rate. Although a single measure of inflation is required for monetary policy analysis, it is often not clear if the possible alternatives, such as consumer price (CPI) inflation, PCE inflation, GDP deflator inflation, core CPI inflation and so on, should be used¹⁰¹ (Kozicki, 1999).

Correspondingly, central bank policymakers face a large amount of uncertainty about the current state of the economy at the time they choose interest rates. In this context, three questions will be investigated, as follows. Firstly, what is the nature of data uncertainty and the implications of this for the conduct of monetary policy? Secondly, what measurement issues are faced by policymakers, and how large are measurement errors (especially, in the case of Korea)? Thirdly, how are optimal Taylor rules affected by data uncertainty?

The remainder of the chapter proceeds as follows. Section 5.2 investigates the nature of data uncertainty that may influence monetary policy-making when using simple policy rules. In Section 5.3, the Taylor rules with noisy data and the central bank's loss function will be presented. Section 5.4 discusses the measures for the output gap, which are frequently used by central bankers, and inflation data series. In Section 5.5, we attempt to

¹⁰¹ The price index used by Taylor (1993) in the Carnegie Rochester paper was the GDP deflator. In the Taylor rule, the measure of inflation is the percent change in the GDP deflator over the previous four quarters. Other researchers have used the inflation measure based on the consumer price index (CPI). Over the past fifteen years, the Federal Reserve has emphasised the inflation rate as measured by changes in the price index for personal consumption expenditures (PCE) (Kohn, 2007).

estimate the optimal policy rule and calculate the central bank's loss values under data uncertainty, and present the results. And, conclusion will be given in Section 5.6.

5.2 The Nature of Data Uncertainty Faced by Central Banks

Following Orphanides (2003), consider the simple monetary policy rules, in which the stance of monetary policy is expressed by comparing the short-term real interest rate, r_t , with its long-term real equilibrium level, \bar{r} , at time t .

$$r_t - \bar{r} = \gamma(\pi_t - \pi^T) + \chi(y_t - y^T). \quad (5.1)$$

This rule specifies that the central bank sets the short-term real interest rate as a linear function of the difference between the actual inflation rate, π_t and its target level, π^T , and deviations of the output gap, y_t , from its target level, y^T . Based on the Fisher equation, *i.e.* $i_t = r_t + E_t\pi_{t+1}$, the short-term real interest rate, r_t can be defined as the short-term nominal policy interest rate, i_t , *minus* the expected future inflation, $E_t\pi_{t+1}$, that is, $r_t = i_t - E_t\pi_{t+1}$.

Assuming that $E_t\pi_{t+1} = \pi_t$, and rewriting Equation (5.1) in terms of the nominal policy interest rate, i_t , gives the following Taylor-type interest rate rule¹⁰²:

$$i_t = \kappa + \theta(\pi_t - \pi^T) + \chi(y_t - y^T), \quad (5.2)$$

¹⁰² The classic Taylor rule is expressed as $i_t = \bar{r} + \pi_t + a(\pi_t - \pi^T) + by_t$, where $\bar{r} = \pi^T = 2$ and $a = b = 0.5$. And, i_t denotes the actual values of US Federal Funds rate (short-term), π_t the rate of inflation, y_t the output gap, \bar{r} the equilibrium or natural rate of interest, and π^T the inflation target. See Taylor (1993) for a more detailed explanation.

where the constant term κ stands for the long-term nominal equilibrium interest rate level, which is defined as $\kappa = \bar{i} = \bar{r} + \pi^T$, and $\theta = (1 + \gamma)$.

The data uncertainty associated with this simple policy rule is that the performance of the reactive rules is normally examined under the assumption that the central bank knows for sure the true values of inflation, π_t and the output gap, y_t , when setting its policy interest rates. However, there may be errors in measuring both inflation and (especially) the output gap are normally measured with considerable errors. In consequence, inflation, $\tilde{\pi}_t$ and the output gap, \tilde{y}_t which are observed by the central bank when its policy choices are made, may be different from the true underlying levels of inflation, π_t , and the output gap, y_t .

Following Rudebusch (2001) and Orphanides (2003), let ξ_t denote the measurement error in true inflation, π_t , and μ_t denote the error in the true output gap, y_t . Then, we get:

$$\pi_t = \tilde{\pi}_t + \xi_t, \quad (5.3)$$

and

$$y_t = \tilde{y}_t + \mu_t, \quad (5.4)$$

where $\tilde{\pi}_t$ and \tilde{y}_t represent noisy observations (real-time estimates of inflation and the output gap); and the errors, ξ_t and μ_t , have means zero, standard deviations, σ_ξ and σ_μ , respectively, and they are by construction correlated with π_t and y_t while assumed uncorrelated with $\tilde{\pi}_t$ and \tilde{y}_t . The errors, ξ_t and μ_t , contain data revisions as well as

forecast errors.

In addition, as mentioned earlier, the true real interest rate, r_t , is not the observed difference between the nominal interest rate, i_t and real-time observed inflation, $\tilde{\pi}_t$, but the unobserved difference between the nominal interest rate, i_t and true inflation, π_t . Hence, in the presence of measurement error, it is evident that the proper form of a simple policy rule specified to set the policy interest rate in terms of observed inflation and the output gap differs from Equation (5.2), but rather:

$$i_t = \bar{i} + \theta(\tilde{\pi}_t - \pi^T) + \chi(\tilde{y}_t - y^T). \quad (5.5)$$

When there is no measurement error, of course $\pi_t = \tilde{\pi}_t$ and $y_t = \tilde{y}_t$ in which case Equations (5.2) and (5.5) are identical. Assuming $y^T = 0$ ¹⁰³ and rearranging Equation (5.5) in terms of the true values of inflation, π_t and the output gap, y_t , the interest rate policy rule corresponding to the rule (5.5) is given by:

$$i_t = \bar{i} + \theta(\pi_t - \pi^T) + \chi y_t - [\theta\xi_t + \chi\mu_t], \quad (5.6)$$

where the size of noise is measured as ' $\theta\xi_t + \chi\mu_t$ '. The nature of data uncertainty problem is revealed by Equation (5.6). Setting the policy rate positively in reaction to an increase in inflation or the output gap since it is judged that such policy choices are needed for the stabilisation of inflation or the output gap, may cause undesirable

¹⁰³ In the model, since the variable y^T means the output gap not output, the target output gap y^T is normally assumed to be 'zero'.

fluctuations in the interest rate, which could have an adverse impact on inflation or the output gap again. Consequently, an efficient policy that takes into account the existence of data uncertainty might call for less aggressive stance in policy-making than would be the case in the absence of data uncertainty, so that policy rule parameters might be affected by possible data uncertainty.

5.3 The Model

To consider substantial data uncertainty confronting policymakers, it is appropriate to incorporate data uncertainty directly within the model. To this end, we set up the model that is a slightly modified version of the canonical model of Svensson (1997 and 1999a), which is composed of two structural equations describing the economy, and the interest-rate rule equation.

In this section, first of all, we introduce two equations: a Phillips curve and an IS curve. In turn, using these two equations, we derive the optimal monetary policy rule¹⁰⁴.

5.3.1 The Structure of the Economy

Consider two equations that represent the transmission mechanism of monetary policy to economic activities in a closed economy¹⁰⁵:

$$\pi_{t+1} - \pi^T = a(\pi_t - \pi^T) + by_t + \varepsilon_{t+1}, \quad (5.7)$$

and

$$y_{t+1} = cy_t - d(r_t - \bar{r}) + \eta_{t+1}, \quad (5.8)$$

¹⁰⁴ The derivation of the optimal policy rule relies largely on Srou (2003).

¹⁰⁵ Both equations are quite a standard model in the literature – that is, they are also used, for example, in Ball (1997), Rudebusch (2001 and 2005) and Rudebusch and Svensson (2002), and others.

where coefficients a , b , c and d are assumed to be positive; ε_t and η_t are disturbances drawn from independent normal distribution with zero means and variances σ_ε^2 and σ_η^2 (i.e., white noise random shocks); the real interest rate is defined as $r_t = i_t - E_t \pi_{t+1}$, where i_t is the short-term nominal interest rate and $E_t \pi_{t+1}$ is expected inflation over time $t+1$, which is formed at the end of time t ; \bar{r} is the equilibrium real interest rate (assumed to be constant). Equation (5.7) is a Phillips curve assuming that inflation, π_{t+1} , depends on the lagged inflation, π_t , the lagged output gap, y_t and a supply shock, ε_{t+1} . Equation (5.8) is an IS curve assuming that the output gap, y_{t+1} , is affected by the lagged output gap, y_t , the lagged real interest rate, r_t , and a demand shock, η_{t+1} . Of course, the output gap is assumed to be inversely related to the lagged real interest rate.

5.3.2 The Optimal Policy Rules

The objective of monetary policy is to minimise in each period t a discounted weighted sum of expected deviations of inflation and the output gap from their respective targets¹⁰⁶:

$$\min_{\{i\}} E_t \sum_{k=0}^{\infty} \delta^k L_{t+k}, \quad 0 < \delta < 1 \quad (5.9)$$

where

$$L_t = \frac{1}{2} [(\pi_t - \pi^T)^2 + \lambda y_t^2], \quad 0 \leq \lambda \leq 1. \quad (5.10)$$

¹⁰⁶ In other words, it is assumed that monetary policymakers have a twofold objective of minimising of deviations of actual inflation from its target level, π^T and variation in the output gap from its desired level, y^T .

subject to the constraint expressed by Equation (5.7) and (5.8). The parameter, δ and λ , are the same as in Chapter 4. The above loss function is fairly standard in the literature (for example, Rudebusch and Svensson, 1999; Smets, 2002; Rudebusch, 2001 and 2002a; Williams, 2004; Orphanides and Williams, 2008).

In the model, the monetary policy instrument determines the (expected) output gap with a one-period lag, and in turn the output gap affects inflation with a one-period lag as well. This causal chain of relationships among variables means that monetary policy has an impact on inflation with a two-period lag. Hence, when $\lambda = 0$ the central bank as a strict inflation targeter should set the instrument in each period so that the two-period ahead inflation expectation is equal to its inflation target¹⁰⁷:

$$E_t \pi_{t+2} = \pi^T. \quad (5.11)$$

Given structural constraint equations (5.7) and (5.8), $E_t \pi_{t+2}$ can be expressed as a function of the state variables and the monetary instrument in each period t :

$$E_t(\pi_{t+2} - \pi^T) = a(E_t \pi_{t+1} - \pi^T) + bcy_t - bd(r_t - \bar{r}). \quad (5.12)$$

¹⁰⁷ This central bank's decision is identical to Svensson (1997)'s result. Since the key policy rate chosen in each period of time affects inflation two periods ahead, the policymaker's problem is to minimise the following loss function:

$$L_t = E_t \delta^2 \frac{1}{2} (\pi_{t+2} - \pi^T)^2$$

The first-order condition for minimising the above loss function with respect to r_t is

$$\begin{aligned} \frac{\partial E_t \delta^2 \frac{1}{2} (\pi_{t+2} - \pi^T)^2}{\partial r_t} &= E_t [\delta^2 (\pi_{t+2} - \pi^T) \frac{\partial (\pi_{t+2} - \pi^T)}{\partial r_t}] \\ &= -\delta^2 bd E_t (\pi_{t+2} - \pi^T) = 0. \end{aligned}$$

It follows that the F.O.C. can be written as $E_t \pi_{t+2} = \pi^T$.

In practice, IT countries are concerned with both inflation and output gap stability, and so $0 < \lambda \leq 1$. If the output gap could be controlled directly by the central bank, its policymakers can determine the output gap in the following period by setting the real interest rate and the output gap in the current period, *i.e.*, $E_t y_{t+1} = cy_t - d(r_t - \bar{r})$. This implies that the policymaker chooses $E_t y_{t+1}$, taking $E_t \pi_{t+1}$ as given. $E_t y_{t+1}$ chosen by the policymaker can be expressed as a function of $E_t \pi_{t+1}$. Since the model is linear-quadratic, it can be shown that the optimal policy rule will take the linear form:

$$E_t y_{t+1} = \ell_0 E_t (\pi_{t+1} - \pi^T), \quad (5.13)$$

where ℓ_0 is a positive parameter to be determined¹⁰⁸. Taking the expected value of the Phillips curve (5.7) and plugging Equation (5.13) into it, the optimal rule can be rewritten as:

$$E_t (\pi_{t+2} - \pi^T) = \ell (E_t \pi_{t+1} - \pi^T), \quad (5.14)$$

where $\ell = a - b\ell_0$ measures the optimal speed at which the central bank should bring inflation back to the target following a shock¹⁰⁹.

Using Equations (5.7), (5.8), (5.12) and (5.14), the optimal rule can be expressed as:

¹⁰⁸ The parameter, ℓ_0 , depends on the models's parameters, a and b , the discount factor, δ , and the policy-maker's weight, λ , which is placed on the output-gap stability relative to inflation stability, as below:

$$\ell_0 = \frac{-\lambda + \delta \lambda a^2 - \delta b^2 + \sqrt{(\lambda - \delta \lambda a^2 - \delta b^2)^2 + 4\delta^2 \lambda a^2 b^2}}{2\delta \lambda ab}.$$

See Svensson (1997) and Lansing and Trehan (2003) for the derivation of this term.

¹⁰⁹ The basic algebraic manipulation shows that ℓ is a constant between 0 and a , and it increases with a which measures inflation persistence. And, the response coefficients γ_r^{op} and χ_r^{op} in the optimal rule also increase with a : a larger coefficient, a , implies that inflation is more persistent, and therefore ℓ will become greater. See Srouer (1999, and 2003) for a more detailed explanation.

$$r_t - \bar{r} = \frac{a(a - \ell)}{bd} (\pi_t - \pi^T) + \frac{a - \ell + c}{d} y_t. \quad (5.15)$$

Defining $\theta_r^{op} = \frac{a(a - \ell)}{bd} (> 0)$ and $\chi_r^{op} = \frac{(a - \ell + c)}{d} (> 0)$, we have:

$$r_t - \bar{r} = \theta_r^{op} (\pi_t - \pi^T) + \chi_r^{op} y_t. \quad (5.16)$$

Or, alternatively, the optimal rule can be written in terms of the nominal interest rate, i_t as follows:

$$i_t - \bar{i} = \theta_n^{op} (\pi_t - \pi^T) + \chi_n^{op} y_t, \quad (5.17)$$

where $\theta_n^{op} = \theta_r^{op} + a > a$, $\chi_n^{op} = \chi_r^{op} + b > 0$, and $\bar{i} = \bar{r} + \pi^T$, where \bar{i} denotes the long-term nominal equilibrium interest rate level. In Equations (5.16) and (5.17), the subscripts, r and n denote parameters for the the real and nominal interest rates, respectively. The optimal policy rule in Equation (5.17) has the same form as the one proposed by Taylor (1993), except of course that the reaction parameters may differ.

5.3.3 The Taylor Rules with Noisy Data

Given the aggregate demand and supply relationships in Equations (5.7) and (5.8), suppose that the policymaker uses the real-time Taylor rule based on Equation (5.17), which is given by:

$$i_t = const + \theta_n^{op} (\tilde{\pi}_t - \pi^T) + \chi_n^{op} \tilde{y}_t, \quad (5.18)$$

where the constant term $const = \bar{i}$, the state variables $\tilde{\pi}_t$ and \tilde{y}_t are inflation and the output gap measured by the central banks in real time¹¹⁰. Following Rudebusch (2001) and Orphanides (2003), we assume that $\pi_t = \tilde{\pi}_t + \xi_t$ and $y_t = \tilde{y}_t + \mu_t$, where ξ_t and μ_t are measurement errors in inflation and the output gap, respectively. In other words, the real-time inflation $\tilde{\pi}_t$ measured by the central banks when deciding its interest rate instrument may deviate from the true inflation, π_t , and in the same manner, the real-time output gap, \tilde{y}_t , measured by the central banks may deviate from the true output gap, y_t .

5.4 Data and Measurement Issues

It is unrealistic to pretend that policymakers can react to the true values of current-period realisations for nominal and real GDP, or the current inflation rate. Furthermore, measures of the underlying state of the economy, for example, the output gap and inflation, are subject to measurement problems unlike interest rate data series. In this section, the measures for the output gap, which are frequently used by central bankers, will be constructed, and inflation data series will be generated as well.

5.4.1 Measuring the Output Gap

Precisely speaking, real-time data refer to data available to policymakers when they make their policy decisions. But it is difficult to obtain real-time data that are used in

¹¹⁰ The target output gap y^T is assumed to be ‘zero’, so that $const = \bar{i}$.

policy decision making. In many cases, hence, alternative variables of potential output and the output gap are constructed by using estimated techniques. There exists a lot of uncertainty regarding the measurement of potential output and the accompanying output gap¹¹¹. These uncertainties are reduced only slowly but perhaps never completely in terms of their measurements. Therefore, data of the output gap are revised necessarily and frequently.

There are two types of uncertainty, which are related to the problems with the measurement of the output gap: model uncertainty and data uncertainty. In this section, model uncertainty is defined as uncertainty regarding the appropriate definition of potential output and the output gap. Data uncertainty occurs because data such as actual and potential output are not available in real time and these data are revised frequently until their final publication: the data available in real time might not be the same as the final published data. Much of the previous literature, including Taylor (1993) and Rotemberg and Woodford (1997), use deviations of real GDP from its fitted time trend for the output gap. Their methods rely on the implicit estimation of potential output as the fitted linear time trend. But, the problem is that potential output can be defined in many different ways and their estimation methods are highly controversial.¹¹² The two different approaches to determining potential output are often used: the production function approach and the HP filtering estimation. The former that uses production functions¹¹³ to determine potential output and the output gap requires a lot of

¹¹¹ Existing literature, for example, Orphanides and van Norden (1999), and Gerlach and Smets (1999), has shown that the output gap is estimated with a considerable margin of uncertainty.

¹¹² These are very important issues. But this chapter will not pay attention to them, because they are beyond of the scope of this chapter.

¹¹³ One example of production function is a constant-returns-to-scale Cobb-Douglas production function, $y^* = A$

information: an assumption on the production technology, information on the equilibrium levels of capital stock and employment. Therefore, this method may not be used frequently, or in real time. Due to this practical reason, many central bankers rely on the HP filtering method to obtain real time estimates of potential output and its corresponding output gap¹¹⁴.

When constructing real time data, both model uncertainty and data uncertainty should be taken into account. But model uncertainty is ignored because it is beyond the scope of this chapter. Following Adema (2004) and Fujiwara *et al.* (2007), real time estimates for potential output and the corresponding output gap are constructed. Above all, the *real-time* estimate of potential output at a certain quarter is obtained by applying a HP filter to real GDP time-series up to that quarter. Prior to applying the HP-filter, the sample is extended with ARIMA-based forecasts of the real GDP series in order to address the end-of-sample problem of the HP filter.

And then, the filtering span is extended by one quarter when a new observation is added to the previous data set. This new data set is used to compute the next quarter's potential output. This process is repeated until all the sample points are used in sequence. The last quarter's estimate obtained at each step becomes the potential output at that quarter. Collecting in time order these estimates yields the *recursive* estimates of potential output. In this chapter, they will be called real time data¹¹⁵ that the

$K^\alpha L^{1-\alpha}$, where y^* is the level of potential output, and A , K and L denote trend total factor productivity, the equilibrium capital stock and employment, respectively.

¹¹⁴ The use of this filter has several problems in that it has no explicit foundation in any economic theory; a long lasting positive (or negative) output gap is ruled out a priori by the HP-filter; and there is an end-of-sample problem when a HP-filter is applied to estimate a potential GDP (Chagny and Döpke, 2001).

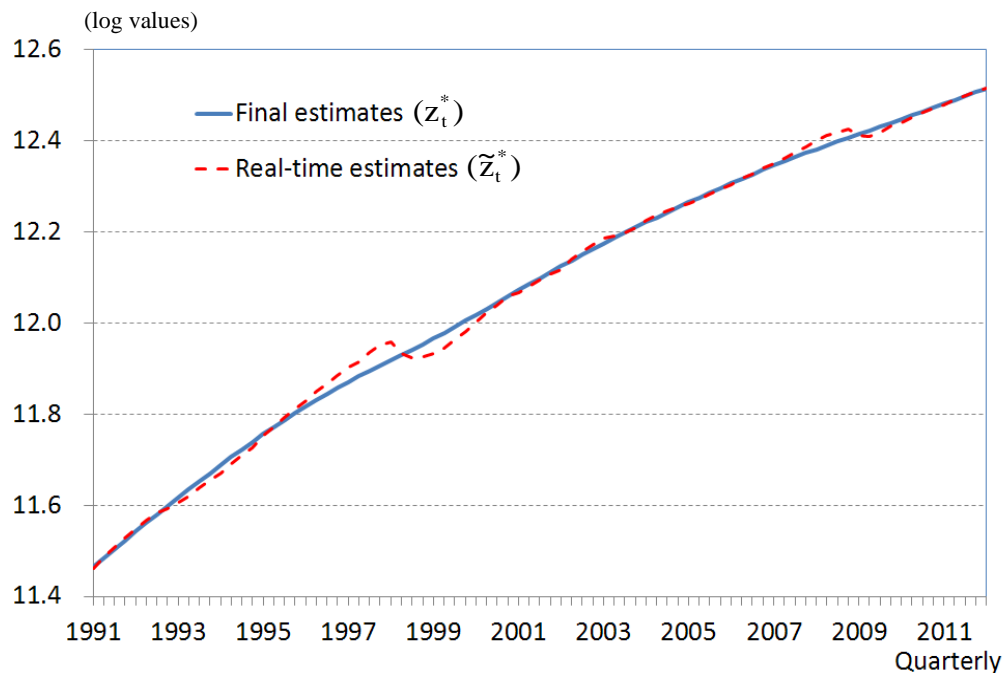
¹¹⁵ In Adema (2004) and Duarte *et al.* (2003), these data are called *quasi-real time* estimates because the sub-samples are drawn from the final dataset.

policymakers rely on. For example, the real-time data for the potential output in 2008:q1 is measured using the real GDP up until 2008:q1, and that for the potential output in 2008:q2 is measured by using the real GDP up until 2008:q2, and so on. Next, the *final* data of potential output are obtained by simply applying the HP filter to real GDP time-series data for the period of 1970:q1 up to 2011:q4.

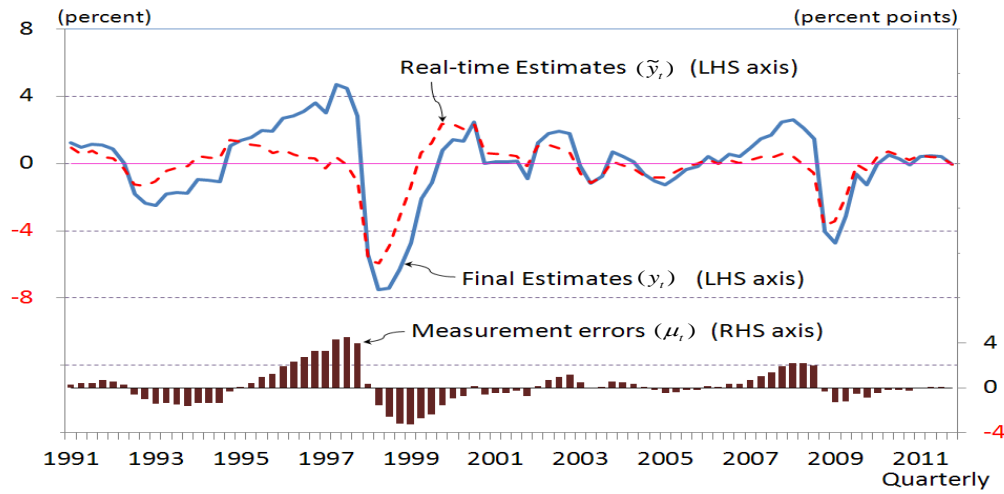
Figure 5.1 depicts two types of time-series estimates for the log value of potential output, z_t^* and \tilde{z}_t^* (Panel A), and the output gaps, y_t and \tilde{y}_t (Panel B), respectively. These two types of estimates for potential output are plotted in Panel A of Figure 5.1 from 1991:q1 to 2011:q4.

Figure 5.1: Potential Outputs and Measurement Errors of the Output Gaps

Panel A. Potential output



Panel B. The output gaps and measurement errors



Note: The lower portion of Figure denotes the time-series estimates of measurement errors, μ_t , which are calculated by the subtraction of real-time estimates of the output gap from final estimates of the output gap.

These two types of estimates for potential output are used to calculate their corresponding two types of output gaps: $y_t = (z_t - z_t^*) * 100$ and $\tilde{y}_t = (\tilde{z}_t - \tilde{z}_t^*) * 100$, where z_t stands for the log value of *final* actual output, z_t^* the log of *final* estimates of potential output, and \tilde{z}_t the log of *real-time* actual output and \tilde{z}_t^* the log of *real-time* estimates of potential output. The resulting data series of deviations from trend, y_t and \tilde{y}_t , constitute the *final* estimates and the *real-time* estimates for the output gap, respectively. Since $y_t = \tilde{y}_t + \mu_t$, this retroactive revision in the output gap from the *real-time* estimates to the *final* estimates generates the measurement errors, μ_t . In general, the real-time estimates of the output gap may be greatly revised retroactively when applying the HP filter again after the arrival of new data.

As seen in Panel B of Figure 5.1, the real-time estimates of the output gap differ from the final ones. Such difference occurs mainly due to frequent revisions and conceptual

changes¹¹⁶ pertaining to measures of *actual* output. Together with these factors, historical revisions and conceptual changes in *potential* output are also reflected in revisions of the output gap since output-gap estimates reflect measures of both actual and potential output at the same time. Notably, the lower portion of Panel B displays the historical degree of error in measures of the output gap. From this, we know that the output gap has a tendency to show systematic one-sided measurement errors in some sample, especially in the periods of between economic contraction and recovery: for example, in the aftermath of Korean currency crisis of 1997–1998 and the GFC of 2007–2009.¹¹⁷

5.4.2 Measuring Inflation

As already mentioned in the introduction of this chapter, inflation can be defined and measured in a variety of methods such as CPI inflation, core inflation and GDP deflator inflation. Inflation measurement has been a particularly difficult and controversial issue in terms of research and economic policy.¹¹⁸ There has been much discussion on the suitable measures of overall inflation in Korea as well. In many cases, these measures of inflation can be used complementarily one another for the actual conduct of monetary policy. The Bank of Korea (BOK) uses CPI inflation rate for a basic measure of the inflation rate.

There are three sources for the real-time inflation data based on CPI in Korea. The first source is the “*Monetary Policy Report*” which is published by the BOK and submitted to the National Assembly on a semi-annual basis, that is, every March and

¹¹⁶ Note that before 1992, the measure of output was GNP (gross national product), not GDP (gross domestic product).

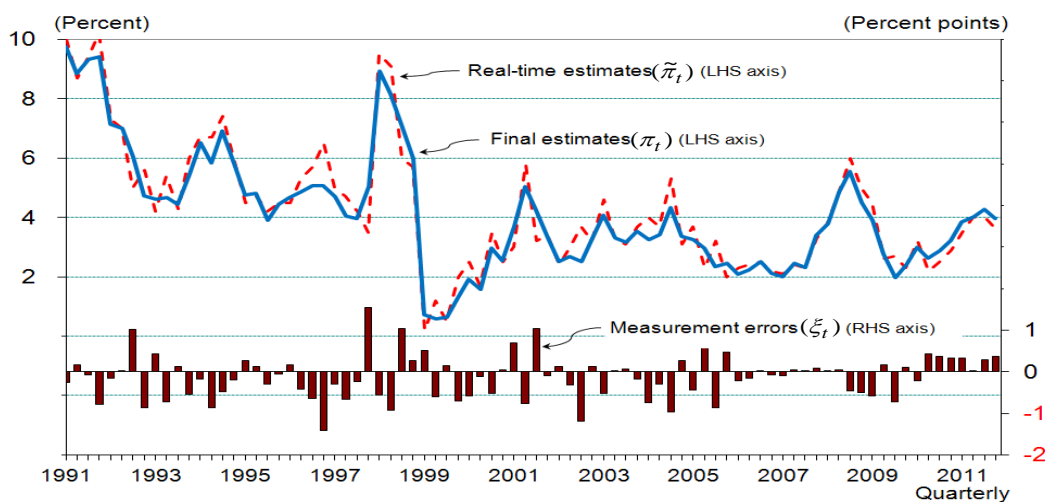
¹¹⁷ Rudebusch (2001) also found that data-measurement errors, in particularly the output gap, are quite persistent over time. He argued that this is not surprising because the main source of uncertainty as to the output gap is the inability to determine the trend growth of potential output, and because errors in setting this trend affects the level of the output gap in adjacent quarters.

¹¹⁸ See Lebow and Rudd (2006) for implications of inflation measurement for research and policy.

September. The second is the “*Economic Outlook*” which is normally released by the BOK in every June and every November. The last one is the “*Current Economic Developments in Korea*” which is prepared for the Monetary Policy Committee (MPC) meeting every month. Referring to these three sources provides the real-time estimates for CPI inflation data that the policymakers rely on in setting the interest rate instrument. In this regard, it is much easier to obtain real time data on the inflation rate relative to those on the output gap. Notice that these three reports do not contain real-time data on the output gap, instead providing only real-time data for growth rates.

Figure 5.2 compares the time-series of estimates of $\tilde{\pi}_t$ which were made in real time by the policymakers in Korea with those of final estimates for inflation, π_t which is released by the Statistics Korea. These two data provide the time-series estimates for ξ_t , which are assumed to be the noise in the inflation measures faced by the central bank policymakers in every quarter from 1991:q1 to 2011:q4.

Figure 5.2: Inflation and its Measurement Errors



Note: The lower portion of Figure denotes the time-series estimates of measurement errors, ξ_t , which are calculated by the subtraction of real-time estimates of inflation from final estimates of inflation.

As plotted in the lower portion of Figure 5.2, the noise in inflation data series appears to be a relatively minor issue in comparison with that in the output gap. However, measurement errors in inflation data are not trivial for the central bank policymakers at all in that inflation traditionally enters with bigger weights in the monetary policy rule, *i.e.*, inflation goal is more important than output goal. The real-time data series sometimes overstate or understate the final inflation estimates. Moreover, any discrepancy between the real-time and final estimates often exceeds one percentage point, especially in the period of 1997–1998 and in the mid-2008. Hence, these spreads between the two estimates can possibly lead to large differences in the policy rule prescriptions based on the real-time and the final data.

5.4.3 Descriptive Statistics

Table 5.1 reports summary statistics for the time-series of the output gap, inflation and their noises from 1991:q1 to 2011:q4. As would be expected for noisy data, the standard deviations (2.103) of real-time data series $\tilde{\pi}_t$ are slightly greater than that (2.003) of the final data series π_t , while the standard deviations (1.419) of real-time data series, \tilde{y}_t , is smaller than that (2.353) of the final data series, y_t . The noise in the inflation data, ξ_t is different from zero on average, ranging from -1.423 to 1.552 percentage points. However, any significant serial correlation patterns cannot be found: the first order serial correlation coefficient is -0.157.

In contrast to inflation data, the output-gap noise exhibits a different pattern. The difference between the final and the real-time output gaps, μ_t , is quite considerable at

times, ranging from -4.674 to 4.697 percentage points, and exhibits strong serial correlation in the sample of data series. The noise process for the output gaps exhibits considerable persistence stemming from both persistent errors in the measurement of actual output and potential output: the first order serial correlation coefficient is 0.894. The existence of this persistence can be confirmed by the estimation result of a first-order autoregression (AR(1)) process for the output-gap noise, μ_t , which is given by:

$$\mu_t = 0.901\mu_{t-1} + \omega_t, \text{ where } \omega_t \sim i.i.d. N(0, \sigma_\omega^2) \quad \hat{\sigma}_\omega = 0.662. \\ (0.048)$$

The 0.901 point estimate for the output-gap noise persistence parameter reveals the substantial serial correlation in the output-gap noise. Interestingly, this regression coefficient is larger than those of the output gaps (0.818 and 0.806, respectively). In other words, the measurement errors of the output gap are more serially correlated than the output gap itself. This means that we can predict, to some extents, data revisions in the measurement errors of the output gap, given that the measurement error follows an AR(1) process, $\mu_t = \rho\mu_{t-1} + \omega_t$.

Moreover, the measurement errors in the output gap during 1991:q1–2011:q4 have a relatively larger standard deviation of 1.541 percentage points, which is a sizeable number in comparison with that of the actual output gap itself for the same period, 2.353 percentage points. This fact implies that it is extremely hard to measure the output gap accurately and robustly in real time, particularly around the end of the data

sample. As in most other countries¹¹⁹, one of the important sources regarding data uncertainty in Korea is the errors in the measurement of the output gap.

Table 5.1: Descriptive Statistics, 1991:q1–2011:q4

	y_t	\tilde{y}_t	μ_t	π_t	$\tilde{\pi}_t$	ξ_t
Mean	0.013	0.270	-0.257	4.140	4.267	-0.127
Std Dev	2.353	1.419	1.541	2.003	2.103	0.523
Minimum	-7.488	-5.527	-4.674	0.594	0.200	-1.423
Maximum	4.707	3.012	4.697	9.744	10.200	1.552
AR(1)	0.818	0.806	0.894	0.824	0.730	-0.157

Notes:

1. y_t is the final estimates of the output gap, defined as actual output minus potential, in percent, based on data available at the fourth quarter of 2011. \tilde{y}_t is the corresponding real-time measure. And μ_t is the difference between the final and real-time output gaps.
2. π_t is CPI inflation, compared with the same period of the previous year, in percent, based on data available at the fourth quarter of 2011. $\tilde{\pi}_t$ is the corresponding real-time measure. And ξ_t is the difference between the final and real-time inflation series.
3. The statistics shown for each variable: Mean, the mean; Std Dev, the standard deviation; and AR(1), the first-order serial correlation coefficient.

5.5 Estimation of Optimal Policy Rules and Results

5.5.1 Parameter Estimation

In order to sketch parameter values for inflation and the output gap equations, Equations (5.7) and (5.8) are estimated with a least-squares regression (OLS), using the quarterly Korean data for the sample period of 1991:q1 to 2011:q4.

¹¹⁹ According to Orphanides *et al.* (2000), the standard deviation of the output gap measurement errors in the United States was 3.77 percentage points during 1966:q2–1994:q4 and 1.77 percent during 1980:q1–1994:q4. The standard deviation of the measurement error in output gap for Japan during 1986–1995 is 1.9 percentage points (Fujiwara *et al.*, 2007).

$$\pi_{t+1} - \pi^T = 0.756(\pi_t - \pi^T) + 0.089y_t + \varepsilon_{t+1}, \quad \hat{\sigma}_\varepsilon = 0.890, DW = 1.63, \bar{R}^2 = 0.54$$

(0.081) (0.044)

$$y_{t+1} = 0.849y_t - 1.656(r_t - \bar{r}) + \eta_{t+1}, \quad \hat{\sigma}_\eta = 1.225, DW = 1.43, \bar{R}^2 = 0.73$$

(0.058) (0.345)

where the figures in parentheses denote coefficient standard errors, and $\hat{\sigma}_\varepsilon$ and $\hat{\sigma}_\eta$ are the standard errors of the residuals for inflation and the output gap equations, respectively. The estimation is conducted by using the final data series since the objective of the model is to capture the movements of inflation and the output gap process. Overall, the empirical fits of the models are considerably good. All regression coefficients on each explanatory variable are statistically significant. Despite their simplicity, the models characterise quarterly Korean data over the sample period. These coefficients are helpful to provide rough information on prior distribution of parameters for the following Bayesian estimation.

Before estimating the models with Bayesian method, four types of monetary policy rules are constructed as below:

$$\text{Rule I : } i_{t1} = \text{const}_1 + \theta_1 (\pi_t - \pi^T) + \chi_1 y_t,$$

$$\text{Rule II : } i_{t2} = \text{const}_2 + \theta_2 (\pi_t - \pi^T) + \chi_2 \tilde{y}_t,$$

$$\text{Rule III : } i_{t3} = \text{const}_3 + \theta_3 (\tilde{\pi}_t - \pi^T) + \chi_3 y_t,$$

$$\text{Rule IV : } i_{t4} = \text{const}_4 + \theta_4 (\tilde{\pi}_t - \pi^T) + \chi_4 \tilde{y}_t.$$

Four policy rules are all variants of the conventional Taylor rules discussed in Subsection 5.3.2. ‘Rule I’ uses *ex-post* final data series for the inflation and the output gap, while ‘Rule IV’ uses real-time data for the inflation and the output gap. ‘Rule II’ consists of the final inflation data and real-time output gap data, and *vice versa* for ‘Rule III’. Each policy rule constitutes the small system of model with inflation and the output gap equations, Equations (5.7) and (5.8) discussed above. For convenience, let us call each system of model Case 1, Case 2, Case 3 and Case 4, respectively: for example, Case 1 consists of the Phillips curve, the IS curve and ‘Rule I’, Case 2 consists of the Phillips curve, the IS curve and ‘Rule II’, and so on.

Turning to the Bayesian estimation, the key reason for adopting this approach is that it easily allows us formalise the use of prior information obtained from previous macroeconometric studies, and as a result, it provides an explicit link with the previous calibration-based literature.¹²⁰ The Bayesian approach yields estimates of the policy reaction parameters along with the structural parameters within the model system at the same time. This method initially maximise the posterior distribution around the mode, and use the Metropolis-Hastings algorithm to draw from the posterior distribution in order to approximate the moments of the distribution and calculate the mean.¹²¹

As stated in An and Schorfheide (2007), in principle priors can be gleaned from one’s introspection to reflect one’s firmly-held beliefs on the validity of economic theories, but in practice most priors are chosen based on some observations considering

¹²⁰ Besides, from a practical perspective, it is known that the use of prior distributions over the structural parameters makes the highly nonlinear optimisation algorithm more stable. See, for example, Smets and Wouters (2003) and An and Schorfheide (2007) for a more detailed discussion.

¹²¹ To this end, we rely on a software *dynare*, which can be downloaded from the website www.dynare.org.

the possible domains and shapes of parameter distribution. The priors on parameters for the Phillips curve and the IS curve are initially set following the values corresponding to those in existing studies¹²². The value of slope coefficient on the Phillips curve, b , is assumed to follow a gamma distribution with a mean of 0.15 and a standard error of 0.01. The value of slope coefficient on the IS curve, d , is also assumed to be gamma distributed with a mean of 1.5 and a standard error of 0.2. The gamma distribution helps to guarantee the positive values of corresponding coefficients. The priors on the parameters $\{a, c\}$ for variables of the Phillips curve and the IS curve are assumed to be beta distributed with a mean of 0.5 and a standard error of 0.2. The beta distribution allows the coefficients to take a positive value between 0 and 1. These specifications are all quite standard calibrations. The priors for the coefficients in the monetary policy rules, θ_j^{op} and χ_j^{op} , are both assumed to be gamma distributed, and they are chosen based on values typically associated with the standard Taylor rule. Particularly, the long-term coefficient on inflation guarantees a unique solution path when solving the model.

On the whole, the estimated posterior parameters appear to be reasonable. The estimated posterior means of the structural parameters and policy reaction parameters are close to the means of the prior assumptions. By and large, most posterior estimates of the parameters are not different from OLS estimates except for the slope parameter, b of the Phillips curve.

The prior distributions and posterior estimates of parameters along with OLS

¹²² See, for instance, Luoto (2009), Smets and Wouters (2003), Taylor (1993), and Rudebusch (2002a,b).

results are reported in Table 5.2.

Table 5.2: Comparisons of OLS Parameters, and Prior and Posterior Parameters

Parameters	OLS results	Prior				Posterior estimates (Mean)			
		Domain	Dist.	Mean	St. Error	Case 1	Case 2	Case 3	Case 4
a	0.756	[0,1)	beta	0.5	0.2	0.703	0.753	0.531	0.574
b	0.089	\mathbf{R}^+	gamma	0.15	0.01	0.154	0.149	0.153	0.149
c	0.849	[0,1)	beta	0.5	0.2	0.504	0.541	0.500	0.541
d	1.656	\mathbf{R}^+	gamma	1.5	0.2	1.500	1.500	1.499	1.501
θ_n^{op}	–	\mathbf{R}^+	gamma	1.5	0.2	1.703	1.619	1.495	1.496
χ_n^{op}	–	\mathbf{R}^+	gamma	0.5	0.1	0.597	0.541	0.551	0.503
\bar{i} (constant)	–	\mathbf{R}	normal	0.05	0.01	0.050	0.051	0.049	0.050

Note: The confidence intervals (*i.e.*, the 5th and 95th percentiles) of the posterior distributions for the Parameters are not reported in Table 5.2.

5.5.2 The Central Bank's Loss Values and Data Uncertainty

Before calculating expected loss values, it is useful to simplify loss function (5.9)-(5.10). As $\delta \rightarrow 1$, the intertemporal loss function, (5.9)-(5.10), can be represented by the unconditional mean of the period loss function, $E[L_t]$ which is equal to the weighted sum of the unconditional variances of the two goal variables:

$$E[L_t] = Var[\pi_t - \pi^T] + \lambda Var[y_t]. \quad (5.19)$$

This is the standard loss function in the literature (Rudebusch, 2005; Froyen and Guender, 2007).

Given each relative weight on the output gap stabilisation, the policy rule (5.17) or

(5.18) assuming the models (5.7)-(5.8) and the loss function (5.9)-(5.10) yields the corresponding loss values. We plug (*ex-post*) final data for the inflation rate and the output gap into *Rule I*, and also into loss function, while plugging real-time data for them into *Rule IV* and the corresponding loss function. In the case of *Rule II*, we plug *ex-post* data for the inflation rate and real-time data for the output gap, and *vice versa* for for the *Rule III*.

Table 5.3 provides the efficient (or optimal) feedback parameters for each of the four policy rules under different assumptions about the degree of data uncertainty, and the expected values of the loss function associated with changes of weights on the goal variables. Notice that policy reaction parameter values came from Table 5.2 that reported posterior means estimated by Bayesian methods within the model systems. Under these parameter values and the relative weight on the output gap stabilisation to inflation rate stabilisation, we calculated the expected loss values. The feedback parameters are said to be optimal as they are the values that minimise the central bank's loss for each case of policy interest rule.

Table 5.3: Optimal Policy Rules and Loss Values under Data Uncertainty

	Data Noise		Rule Parameters		Expected Loss			
	σ_{ξ}	σ_{μ}	θ_j^{op}	χ_j^{op}	$\lambda = 0.75$	$\lambda = 0.50$	$\lambda = 0.25$	$\lambda = 0.00$
<i>Rule I</i>	0.00	0.00	1.703	0.597	4.36	3.28	2.34	1.35
<i>Rule II</i>	0.00	1.54	1.619	0.541	4.45	3.38	2.51	1.51
<i>Rule III</i>	0.52	0.00	1.495	0.551	6.58	4.76	3.13	1.31
<i>Rule IV</i>	0.52	1.54	1.496	0.503	6.60	4.88	2.75	1.45

Notes: 1. σ_{ξ} and σ_{μ} denote the degree of data noise, measured by standard deviations of the noises of inflation and the output gap, respectively.

2. In the notation of rule parameters, the subscript, j takes 1, 2, 3 and 4 for the corresponding model.

Comparing the policy rule parameters, it is by and large found that the greater the degree of data uncertainty, the smaller the size of the optimal rule coefficients. For the case with no data uncertainty, *i.e.*, the (0, 0) pair, the optimal policy rule has coefficients $\theta_1 = 1.703$ and $\chi_1 = 0.597$. However, for the case with data uncertainty, *i.e.*, the (0.52, 1.54) pair, the optimal rule has coefficients $\theta_4 = 1.496$ and $\chi_4 = 0.503$. The cases of the (0, 1.54) and (0.52, 0) pairs on data noises mean the policy rules assuming uncertainty about only one variable, thereby yielding $\theta_2 = 1.619$ and $\chi_2 = 0.541$, and $\theta_3 = 1.495$ and $\chi_3 = 0.551$, respectively.

These results imply that when the policymaker faces an economy like Equation (5.7) and (5.8), he has to choose the θ_j^{op} and χ_j^{op} parameters of the each policy rule so as to minimise the loss value in the presence of such data uncertainty. For comparison, the last four columns for the expected losses show the results according to the degree of data uncertainty. The increasing amount of data uncertainty on the whole leads to the larger expected loss for changes of weights on the goal variables. For instance, in the case with $\lambda = 0.75$, the *Rule IV* with data uncertainty in both the inflation rate and the output gap has an expected loss of 6.60, while the *Rule I* under data certainty has an expected loss of 4.36.

In summary, it is found that the greater the output-gap uncertainty, the smaller the output-gap response coefficients in the optimal rules, and in a similar vein, the greater the inflation uncertainty, the smaller the inflation response coefficients. These findings are in accord with the literature on data uncertainty (for example, Rudebusch, 2001; Svensson and Woodford; 2003; and Orphanides, 2001 and 2003, among others), implying that the central bank under data uncertainty should less actively respond to fluctuations in the

output gap or inflation rate with uncertainty

5.6 Conclusion

Over the past decade and a half, monetary policy guided by simple policy rules has shown good results in simulated models of the macroeconomy, and accordingly much quantitative evidence has continued to accumulate. It may be true that simple policy rules appear to have offered useful baselines for monetary policy discussions. However, it is also true that some researchers have argued that the usefulness of simple rules for policy analyses may collapse when we introduce informational problem pertaining to some of the advocated policy rules.

In this context, on Korean data, we introduced data uncertainty into the derivation of optimal policy rules, and examined how the optimal policy rules change when uncertainty on data increases.

We have shown that it is of great importance for the central bank to consider incomplete information for the conduct of monetary policy. The main finding is that the greater the output-gap uncertainty, the smaller the output-gap response coefficients in the optimal rules, and in a similar vein, the greater the inflation uncertainty, the smaller the inflation response coefficients. Another finding is that the optimal policy rules derived by using data without errors showed the larger size of the output-gap and inflation response coefficients. These findings, in accord with the existing literature on data uncertainty reviewed in Chapter 2, imply that the ideal monetary policy behaviours by the central banks under certainty might be more responsive to economic conditions. In fact, however,

central banks face a large amount of uncertainty about the actual state of the economy when setting their policy interest rates at each period of time. The evaluation of monetary policy in most empirical studies relies on the unrealistic assumption that policymakers know for sure the current state of the economy with no errors. But, the actual monetary policy always involves decisions and judgments that are based on real-time data which are incomplete. As discussed earlier, some measures, especially macroeconomic data such as the output gap and inflation rate, are subject to large and frequent revisions following the initial data release.

In this respect, data uncertainty may be one of the sources explaining the reasons why monetary policymakers react less aggressively in setting their interest rates instrument. Intuitively, in an environment where data uncertainties are rife, an excessively aggressive policy response would induce unnecessary variations in interest rates, leading to undesirable fluctuations in inflation and output. Hence, it is quite natural that central bankers choose a gradual adjustment of policy rates to avoid undue fluctuations of the economy (inflation and real output).

Chapter 6

House Prices and the Effectiveness of Monetary Policy

6.1 Introduction

For several decades before 2007, many advanced countries were relatively successful in keeping inflation at a low and stable level. As a consequence, some central bankers became more confident that they could control economic fluctuations including inflation. During the period from the 1990s through to the early 2000s, many countries adopted an IT regime for their monetary policy framework. Its successful outcomes in curbing inflation led central bankers to believe that they had conquered inflation, moreover to think that they could even flatten business cycles.

Notwithstanding these good outcomes, there was a growing concern that heightened risks of financial instability had been accumulated in the aftermath of the collapse of the dot-com bubble since the late 1990s. In fact, financial imbalances might be hidden

behind low and stable inflation. Rapid financial liberalisations and developments hindered the detection of distortions in the financial markets. During the period of 1980–2007, inflation in the real sector was largely stabilised. However, the prices of assets such as real estate became more volatile than ever before, fluctuating sharply with economic conditions. Consequently, central banks were given a new task to conduct an effective policy to stabilise the financial sector and to minimise macroeconomic instability stemming from large swings in asset prices even in a low and stable price environment (see Allen and Rogoff (2011), among others).

After the summer of 2007, the global economy was faced with more severe financial turmoil than it had ever experienced before. Booms and busts in asset prices led to financial crises and economic recession in many countries. The recent financial crisis gave a chance to revisit an old question: should central banks take into account the changes in the prices of assets – in particular, housing and land – in the conduct of monetary policy? Excessive fluctuations (*i.e.*, booms and busts) in asset prices become a more crucial source of macroeconomic instability in both advanced and emerging countries.

Asset prices are conceptually somewhat different from the prices of current goods and services: they are inherently forward-looking variables in that they reflect the expectations of market participants about the value of future streams of their underlying pay-offs, which implies that they include useful information about future supply and demand conditions. Shifts in asset prices affect household wealth and firms' market valuation, and hence have an impact on consumer spending and firms' investment expenditures, as a result affecting aggregate demand. Consequently, asset prices include

important information regarding the current and future state of the economy and can play an important role in the monetary policy framework aimed at attaining the goals of price stability while also minimising fluctuations in the real economy¹²³.

In general, prices are determined by the fundamentals of supply and demand in the economy. Growth in demand relative to supply comes to be reflected in rising prices. For the assets, we cannot directly observe many of these fundamental factors that affect the market's expectations of future supply and demand. At times, asset prices seem to drift further away from their underlying fundamental determinants. Such a circumstance may indicate that there is a developing bubble in the asset market that will burst at some time in the future. Since historical experience¹²⁴ indicates that boom-bust cycles in asset prices can be damaging to the economy, the following question arises: should central banks directly act earlier to control the sharp increase in asset prices, *i.e.*, prick the bubble?

In this chapter, we build a forward-looking structural model that consists of the Phillips curve, the IS curve and monetary policy reaction rules, forming a small dynamic stochastic general equilibrium (DSGE) model. The advantages of DSGE models are that they can be solved in a system and they allow us to compare the performance of alternative monetary policies under different assumptions. By using them, it is possible for us to see what should be the best response of central banks to changes in asset prices in order to make a positive contribution to achieving economic stability. In this context, the purpose of this chapter is normative differently than Capters 4 and 5 which had a

¹²³ In the conceptual context, this policy framework is commonly known as a flexible inflation targeting. See, for instance, Svensson (2002) and Walsh (2009), among others.

¹²⁴ Most notable examples are the US stock market bubble associated with the advent of a New Economy in the late 1990s, the Japanese real estate market boom-bust in the early 1990s, and the global financial crisis triggered by the US sub-prime market defaults in 2007.

positive intent.

The outline of this chapter is as follows. Section 6.2 looks into major discussions on what implications asset-price volatility has for monetary policy and how monetary policy authorities should respond to this. Before turning to modeling monetary policy actions, Section 6.3 briefly discusses the concept of “excess liquidity” and its measure and examines the relationship of excess liquidity to house-price bubbles; subsequently dealing with a brief overview on the movements of asset prices, and presenting the dynamic correlation between inflation and prices of assets including mainly house and land prices in order to see if there is the precedence of asset prices to inflation in Korea. Section 6.4 formulates the structural model and discusses the model solutions, and explains the estimation procedures. This modelling process here is designed to seek optimal policy actions under the assumption that the central bank responds to house prices. Section 6.5 compares and analyses the effect of monetary policy by using optimal control analysis, to examine which policy choice is more effective in terms of validity between the one pursuing price stability only and the other one considering price stability and asset price volatility together. Section 6.6 concludes and draws policy implications based on the empirical results.

6.2 House Prices and Monetary Policy

6.2.1 The Roles of Housing in the Economy

Regarding the role of asset prices in the conduct of monetary policy, particular attention has to be paid to housing. This is justified by the importance of housing for economic

activity: first of all, housing assets function as durable goods and production factors. That is to say, they provide residential services to households and can be input into production for firms; second, in the case that financial institutions (banks) offer credit to lenders, housing plays a role as collateral for the households, which may be a key factor for a potential amplifying channel on the effects of monetary policy. Likewise, the availability of bank credit to households depends significantly on the collateral of households, which is why credit provision has a positive relationship with house-price movements. In this regard, housing stimulates households' spending activity in line with the improved bank loan availability thanks to the increased value of collateral. In contrast, if the value of a house as collateral declines due to falls in prices, house assets could have a negative impact on consumption of households. This implies that real estate like housing is a transmission channel which not only passes on external shocks into other economic variables through fluctuations in real estate prices, but also acts as a factor leading to business fluctuations; and lastly, the house as an asset in households' investment portfolios provides a potential capital gain for them when its prices rise. In reality, it accounts for a much larger proportion of wealth that households own.

6.2.2 How Important are House Prices in the Monetary Transmission?

Changes in interest rates caused by monetary policy actions have an impact on the domestic aggregate demand both *directly*, by affecting residential construction and households' spending plans via the changes in availability and cost of credit, and *indirectly* by leading to changes in house prices (Mishkin, 1995 and 2001; IMF, 2008).

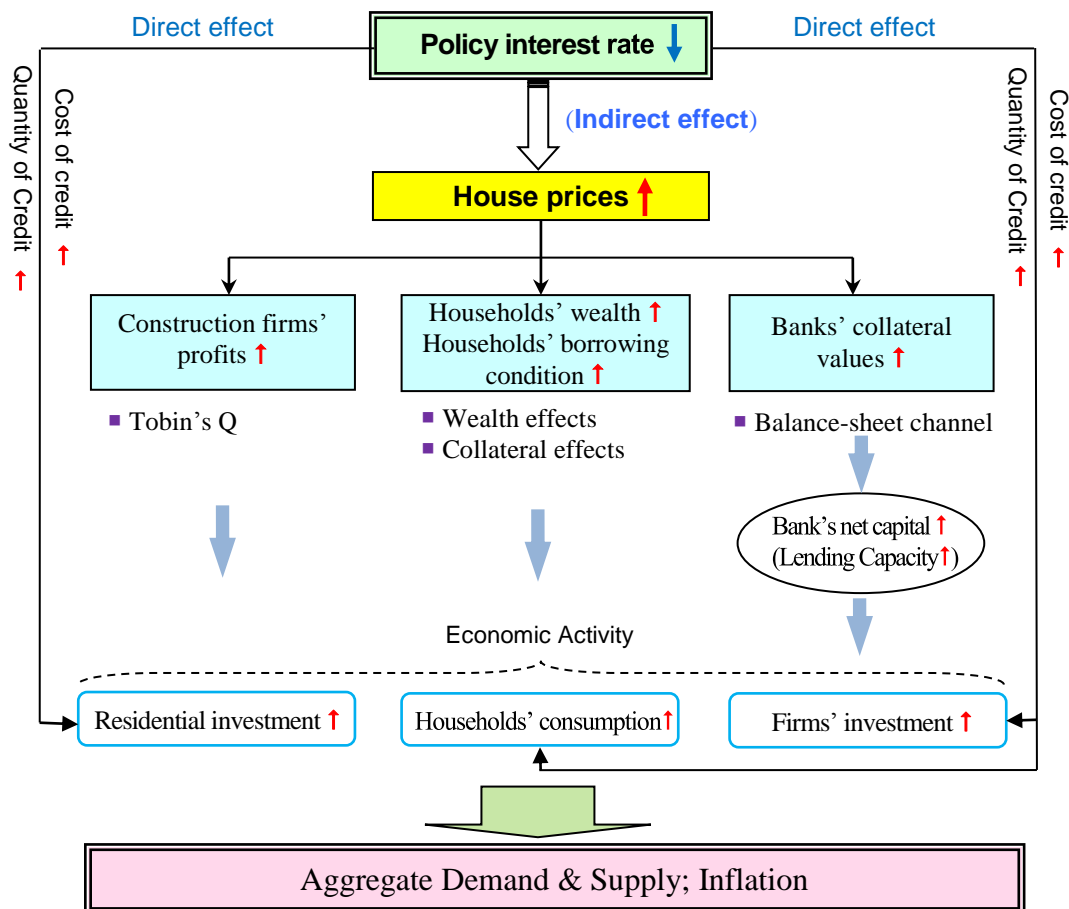
The *indirect* channel can be described in more detail as follows. Firstly, an expansionary monetary policy that lowers interest rates leads the costs of financing housing to decline, as a result of which the demand for housing increases and thus house prices rise. When expansionary monetary policy results in declines in interest rates (return on assets), the demand for a substitute grows. This brings about rises in the price of real estate (*i.e.*, buildings and land owned by households or firms). From the perspective of construction firms, significant rises in house prices compared to the cost of housing construction lead them to increase their supply of housing because the firms' profitability improves (*Tobin's Q*)¹²⁵. As a result, economic agents increase their investment in and consumption of housing, raising aggregate demand and aggregate output. Mishkin (2001) calls this channel a direct effect on housing expenditure.

Secondly, fluctuations in real estate prices affect economic activity through an asset-price channel. In this channel, wealth effects play an important role in consumption theory. According to Modigliani (1966 and 1971)'s life-cycle hypothesis, in periods when there are growing prices in real estate such as home and land, due for example to expansionary monetary policy, households tend to regard their lifetime income (wealth or permanent income) as increasing (*wealth effects*). And, real estate plays a crucial role as collateral that households can offer when they borrow from financial institutions. Household borrowers who have a good financial status (in terms of *balance sheets*) can be offered larger loans with relatively low cost (*collateral effects*). Accordingly, households who witness increased permanent income and an improved borrowing

¹²⁵ Strictly speaking, this is a variant of Tobin's Q-theory in which Q for housing investment is the price of housing relative to its replacement costs (Mishkin, 2001). According to Tobin's Q, the profitability of property investment depends on the ratio between house prices and construction costs.

condition, tend to expand their current consumption by cutting their savings or increasing borrowings even if their income is not on the rise at present.

Figure 6.1: House Prices and the Monetary Transmission Channels
(The case of Declines in Policy Interest Rates)



Note: For simplicity, the figure does not show all interactions between variables.
Source: Adapted from IMF (2008), Mishkin (1995, 2008) and others.

Thirdly, fluctuations in real estate prices affect the macroeconomy through the bank *balance-sheet channel*. When declines in interest rates lead to rises in real estate prices, the value of real estate held as collateral by financial institutions (banks) grows, thereby reducing the consequences of loan defaults as bank capital increases. Likewise, when the

soundness of financial institutions is enhanced, their lending capacity may expand, enabling banks to respond well to the demand for money from households or firms. This results in an expansion in consumption and investment in the economy. On the contrary, decreases in real estate prices reduce collateral values, which contracts the supply of credit by financial institutions (banks), and this leads to decreases in consumption and investment by economic agents. As a consequence, aggregate output declines. In this context, Bernanke and Gertler (1999) introduce the concept of the ‘financial accelerator’ in order to prove the fact that the credit supply by banks is closely related with the business cycle of the housing markets. The transmission channel, which appears when real estate prices sharply fall, is also referred to as the ‘capital crunch’, which could act as a critical factor behind stagnation. Such stagnation occurred in the early 1990s and the late 2000s in the US while it took place in Japan from the early 1990s throughout the 2000s.

6.2.3 Fluctuations in Real Estate Prices and Monetary Policy: Two Views

As fluctuations in the prices of assets including real estate have deepened worldwide since the late 1990s, there have been contrasting views on the necessity of monetary policy responding to these fluctuations.

6.2.3.1 Indirect Responses

Most central banks including the US Federal Reserve Bank and many economists point out that central banks should respond to fluctuations in asset prices only when there is a much higher concern that asset prices are accelerating and as a consequence, threatening price stability. They argue that central banks should not use monetary policy just to

eliminate bubbles in asset prices. This view is known as the so-called “benign neglect” approach.

More specifically, this view reflects the following thoughts. First of all, the correlation between asset prices and interest rates is uncertain, and central banks do not hold appropriate tools to eliminate bubbles only from asset prices. That is, the adjustment of interest rates, which is one of the representative policy tools used by central banks, affects the economy across the board, not just in asset markets. Monetary policy may be too blunt a tool for effectively dealing with bubbles *per se*¹²⁶.

Secondly, it is also important to consider that central banks are faced with uncertainty in assessing the level of asset prices and judging whether there are bubbles in them. Determinants¹²⁷ of asset prices can be also affected by individual subjective expectations as to the degree of uncertainty. For this reason, it is difficult to separate expectation factors from the value of the asset, which is why there cannot help but exist various contrasting views regarding appropriate levels in asset prices. Moreover, as stated by Bernanke and Gertler (1999), it is nearly impossible to know for sure whether given changes in asset prices come from economic fundamentals or not. Greenspan (2002) frequently emphasises the uncertainty in assessing asset prices, thus arguing that it is an illusion for central banks to tackle bubbles in asset prices through policy such as appropriate increases in interest rates, and that it is difficult to distinguish a bubble only

¹²⁶ Regarding this problem, Bernanke (2002) points out: “Certainly there is no way to direct the effects of monetary policy at a single class of assets while leaving other financial markets and the broader economy untouched. One might as well try to perform brain surgery with a sledgehammer.”

¹²⁷ For instance, flow of expected return on assets (for example, dividend, land prices), flow of expected return on investment substitute (government bond), the prices an asset owner expects when reselling assets in the future, and relative risk resulting from owning a specific asset and liquidity.

even if central banks carry out preemptive monetary policy. In the presence of growing uncertainty, it poses a limitation in responding to large surges in asset prices with monetary policy. This is because, as there is a significant bias within an expectation factor which is one of the determinants of asset prices, monetary policy in response to fluctuations in asset prices cannot help but be carried out under uncertainty, which could result in the wrong policy being selected (Greenspan, 1998).

Lastly, it cannot be said that central banks are more capable of interpreting information contained in fluctuations in asset prices than market participants. Moreover, it is unclear if central banks can figure out whether rises in asset prices originate from improved fundamentals or from speculative bubbles¹²⁸.

Poole (2001) argues that the performance of the stock market should not be a direct object for monetary policy of central banks, and insists that any policy measures targeting the stock market *per se* would be self-defeating. Regarding this, he points out the reason that, although it is true that there is useful information on future profitability of firms, fluctuations in stock prices can be affected also by an unreasonable component such as “irrational exuberance”, which does not reflect economic fundamentals (Greenspan, 1996). In other words, as the stock market itself does not always provide reliable information, stock prices should be used in complementing and confirming the information obtained from other sources. Therefore, he argues that, unless it is the case that there is a concern that the market mechanism could be put at risk on account of disorder in financial markets caused by fluctuations in asset prices,

¹²⁸ See, The New York Times (15 November 1998), “Inside the Head of the Fed; Alan Greenspan's Journey to the New World Economy.” Greenspan argues that there exists a fundamental problem in market intervention, which is that the agent who intervenes assumes that he knows better than the market does.

central banks should not target asset prices *per se*¹²⁹. This view is often referred to as the “Greenspan doctrine”¹³⁰.

Bordo and Jeanne (2002a,b) argue that central banks should intervene in bubbles of asset prices in a selective way only when the utility gained by preventing bubble bursts in the future are considered larger than the costs generated by tightened monetary policy. In other words, when bubble formation can be prevented through other policy measures such as supervision and regulation, it is desirable for central banks to refrain from carrying out the tightening of monetary policy which could provoke economic recession.

Bernanke and Gertler (1999 and 2001) and Bernanke (2002) argue that it is undesirable for central banks to respond to fluctuations in asset prices as monetary policy should be concentrated on stabilising expected inflation. But they point out that central banks should consider asset price movements as long as they are helpful in predicting inflation. And they argue that the best policy measure is an adoption of flexible inflation targeting (IT), claiming that, except in situations where fluctuations in asset prices are expected to affect inflation and output, central banks should not respond to fluctuations in asset prices. The reason behind this argument is based on the fact that it is difficult to identify clearly whether rises in asset prices originate from improved economic fundamentals, from non-fundamental factors such as speculative activity, or from both. Rises in asset prices tend to spur aggregate demand while declines in asset prices tend to contract aggregate demand. Therefore, under the IT regime strongly focusing on stabilising aggregate demand including inflation, central banks can pre-emptively

¹²⁹ In fact, for example, the Federal Reserve Bank responded immediately after a plunge in stock markets in October 1987, Russia's declaration of moratorium and bankruptcy of Long-Term Capital Management (LTCM) in August 1998.

¹³⁰ Former Chairman of the Federal Reserve Board, Greenspan often argued that central banks should not try to ‘lean against asset-price bubbles, but rather should clean up after they burst’ (Greenspan, 2002).

respond to asset prices at the early stage in which instability in asset prices occurs (this strategy is also called “leaning against the wind” with respect to booming asset prices). This automatic reaction can achieve to some degree stabilisation of financial markets, together with stabilisation of the economy.¹³¹

Gilchrist and Leahy (2002) argue that, as asset prices are endogenous variables affected by capital stock and industrial productivity, as a whole representing economic conditions, monetary policy should respond directly to the determinants of asset prices rather than to asset prices themselves.

6.2.3.2 Direct Responses

In recent years, it has frequently been witnessed that bubbles in asset prices accelerate inflationary pressures and the bubble bursting generates financial instability, deepening economic recession. For this reason, there are increasing arguments that, even during the period when general prices appear stable, central banks should actively and pre-emptively respond to sharp fluctuations in asset prices in order to stabilise financial markets.

The background behind this view is based on three arguments: first, asset prices become misaligned from underlying fundamentals, and if the misalignments persist for a long time, macroeconomic stability as well as the financial soundness of households and

¹³¹ In this regard, Bernanke and Gertler (1999) point out three reasons: firstly, macroeconomic stability under the circumstances in which there is neither inflation nor deflation contributes itself to financial market stability; secondly, when asset prices decline, central banks’ financial stability-policy can help to offset to some degree the deterioration in balance sheets of households and firms, reducing vulnerability of the economy to negative shocks; and finally, if financial market participants expect central banks to carry out policy focusing on the effects of aggregate demand pressures on inflation, thereby raising (cutting) interest rates in a period of sharp surges (crashes) in asset prices, such a strategy will act as a warning against economic overheating (recession), consequently alleviating overreactions in asset prices arising from non-fundamental forces and market psychology such as investors’ irrational behaviour, for example, herd behavior, excessive optimism or short-termism.

firms could be seriously threatened. In reality, it has been often witnessed that bubbles in asset prices aggravate inflationary pressures and that financial instability worsens when the bubble bursts. Looking into the cases of advanced countries such as the US and Japan, rapid rises in asset prices are commonly based on expansionary monetary policy through banks' excessive credit expansions (Cecchetti *et al.*, 2000). Bubbles in asset prices occur in the following process: escalating prices in assets which are used as collateral for loans, this expands the capacity to lend, leading to increases in credit. Therefore, there is a growing argument that it is necessary to cut the circular linkages of asset-price rises and consequent credit expansion by using tools such as financial system regulation and supervision along with monetary policy (Kent and Lowe, 1997). It implies that a monetary policy response is necessary to prevent the side effects of bubbles in asset prices, even when expected inflation is lower than its target in the short-run. Moreover, bubbles would burst anyway, and notably, when the bubbles burst after growing for a long time, it could have a negative effect on the whole financial system, and this could lead to lower economic growth and deflation, ultimately resulting in a worse recession. And when central banks aggressively respond to fluctuations in asset prices by raising policy rates, this can lower the possibility of the bubble occurring at an early stage, and by doing so, central banks can prevent a worst situation developing, such that fluctuations in asset prices affect inflation and growth. Notably, once a bubble occurs, it is difficult to tackle this with monetary policy only, and when the bubble bursts, it brings about imbalances in the balance sheets of financial institutions and firms, causing the financial system to deteriorate. All these things considered, it is necessary for central banks to take measures to prevent the occurrence of bubbles in asset prices in advance (Goodhart, 1999b).

Second, asset prices play an important role in the monetary transmission mechanism. As bubble booms and busts destabilise financial markets and institutions, which play a crucial function in the transmission channels of monetary policy, and moreover constrain policy effects, it is argued that central banks should actively respond to fluctuations in asset prices. Rises in asset prices expand consumption expenditure through wealth effects and boost firms' investment expenditure through the effects of loans increasing, resulting from the rising value of collateral. Such an expansion of consumption and investment, *i.e.*, increases in aggregate demand may provoke inflationary pressures in the economy. In particular, Blanchard (2000) argues that, it is more desirable for central banks to conduct tighter monetary policy in the presence of bubbles than is implied by inflation targeting, considering the so-called 'composition effects', implying that asset bubbles have larger effects on investment than on consumption.¹³²

Third, the consumer price index (CPI) is theoretically imperfect as an indicator for measuring inflation in that not just current but also future consumer prices of commodities and services have an impact on currency value (Kent and Lowe, 1997). Since physical or financial assets are claims to future consumption, fluctuations in their prices reflect changes in expected future returns which can be gained from those assets. Regarding this,

¹³² According to Blanchard (2000), under the circumstance that aggregate demand pressures aggravate owing to expanded bubbles, the central bank can choose one of two policies: first, it can maintain aggregate demand to a certain level by raising policy rates in order to keep the inflation target. However, such a policy has a problem that brings about a change in the composition of output: investment goes up, but consumption decreases as output may be constant. Bubbles lead to excessive capital accumulation; second, the central bank can target constant investment by increasing interest rates in order to avoid excessive capital accumulation. Because this policy is more aggressive than the first, a recession may be inevitable: investment remains constant, but consumption decreases due to higher interest rates, and so do demand and output.

For the first strategy, once bubbles suddenly burst, it leads to a lot of useless capital, serious collateral problems for firms, and economic recession for some time after the collapse of bubbles. The second strategy may not give rise to this problem. But, such a result is obtained at the expense of tightened policy, and severe recession may occur due to too tightened a policy. Therefore, he claims that the central bank should choose the strategy that is likely to be somewhere in between the two strategies: to take a bit more aggressive policy stance than is suggested by inflation targeting.

Alchian and Klein (1973) argue that, when asset prices fluctuate sharply, the existing consumer prices which do not reflect their fluctuations, distort the signs of prices and consequently provoke an inefficient allocation of resources, adding that it is necessary to create a price index which includes asset price movements. Goodhart (1995, 1999b) and Filardo (2000) also raise similar arguments to those of Alchian and Klein (1973). They argue that central banks' policy goals should be broadened to reflect asset prices. Central banks should give more attention to future fluctuations in prices of commodities and services, whose fluctuations cannot be measured directly. They claim that it is possible to grasp fluctuations in prices of services and commodities by creating a broader measure of inflation that reflects asset price movements.

6.3 House Prices and Bubbles in Korea

This section reviews an explanation of the concept of 'excess liquidity' and its measure. After analysing house-price bubbles using Korean data, we briefly analyse the relationship of excess liquidity to house-price bubbles. Next, we investigate the relationships among house prices and macroeconomic variables such as inflation and the GDP gap in Korea.

6.3.1 The Concept of 'Excess Liquidity'

The 'liquidity' is an elusive term that can be interpreted in different ways. It can be used to describe the presence of money stock in financial markets like money and equity markets. In addition, it also refers to the total quantity of money supplied by the central bank in an economy. In this regard, liquidity is often used to depict the central bank's monetary policy stance (IMF, 2007).

The term 'excess liquidity' is also ill-defined. In fact, excess liquidity has an

immense impact on financial conditions in the economy. It has in particular recently drawn great attention from central bankers and market participants regarding the latest financial crisis. In this case, the concept of liquidity is used to mean “*monetary liquidity*”, associated with low interest rates or much easier borrowing conditions caused by the accommodative stance of monetary policy¹³³.

Monetary liquidity, which is often regarded as linked to conditions in short-term credit markets, is closely connected with short-term interest rates or the aggregate quantity of money. In general, monetary liquidity can be measured as a growth rate of a monetary aggregate (for example, the broad money or M2), or its relative ratio to a base like GDP (for a more detailed discussion, see Baks and Cramer (1999)).

In this context, we can define some terminologies concerning the concept of liquidity. According to existing literature, monetary liquidity is measured as the ratio of a monetary aggregate to nominal GDP, that is, Lf/GDP ¹³⁴, which is called a ‘liquidity/GDP ratio’ (hereafter referred to as the ‘*liquidity ratio*’). Then, the liquidity ratio gaps are defined as the deviations of the liquidity ratio from its long-term trends which are commonly calculated by Hodrick-Prescott (HP) filters.¹³⁵ If the values of the liquidity ratio gaps are greater than those of their long-term trend, it can be said that there exists excess liquidity.

¹³³ In the literature, multiple definitions of liquidity, for example, *monetary liquidity* and *market liquidity*, are often used without careful discernment in their meanings. However, the concept of *monetary liquidity* is different from that of *market liquidity* which usually refers to the ability of financial markets to absorb transitory changes (shocks) in supply and demand, accordingly leading to no large swings in prices or no significant loss of value. Nonetheless, these two concepts are intimately related to one another in that monetary liquidity supports market liquidity: for instance, abundant monetary liquidity tends to bring about increases in market liquidity by lowering the cost of funding (Baks and Cramer (1999). See also BIS (1999) for an overview of the definition and measuring issues of *market liquidity*.

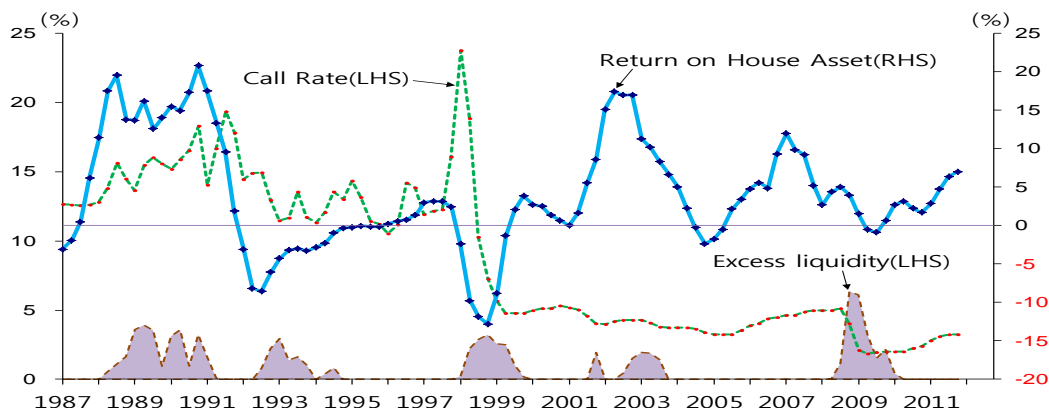
¹³⁴ Here, Lf denotes the liquidity aggregates (stock) provided by all the financial institutions. To get this ratio, seasonally adjusted series of Lf and GDP are used.

¹³⁵ Because of quarterly data, $\lambda=1600$, the smoothing parameter is applied for obtaining long-term trends in the H-P filtering.

Finally, we define only the positive values of the liquidity ratio gaps as ‘excess liquidity’. In periods when there exists excess liquidity in the economy, in other words, when the liquidity ratio is above its trend in the long-run, and *ceteris paribus*, there is a high possibility that asset prices will come to rise, leading to an increase in the return on assets.

Figure 6.2 plots the evolutions of the call rates, excess liquidity and house-price change rates from 1987:q1 to 2011:q4. It is apparent that the Korean economy has experienced at least four occasions of excess liquidity since the late 1990s. The collection of house prices is relatively easier than that in other countries (*e.g.*, U.S.) since they are released every month by a nationwide commercial bank, Kookmin Bank (KB).

Figure 6.2: Trends of Call rate, Excess Liquidity and House Prices
(X-axis in quarters)



Note: The return of house prices is calculated as change rates in house prices compared with the same periods of the previous years.

Sources: ECOS database, The Bank of Korea; and Kookmin Bank Survey.

6.3.2. Excess Liquidity and House-price Bubbles

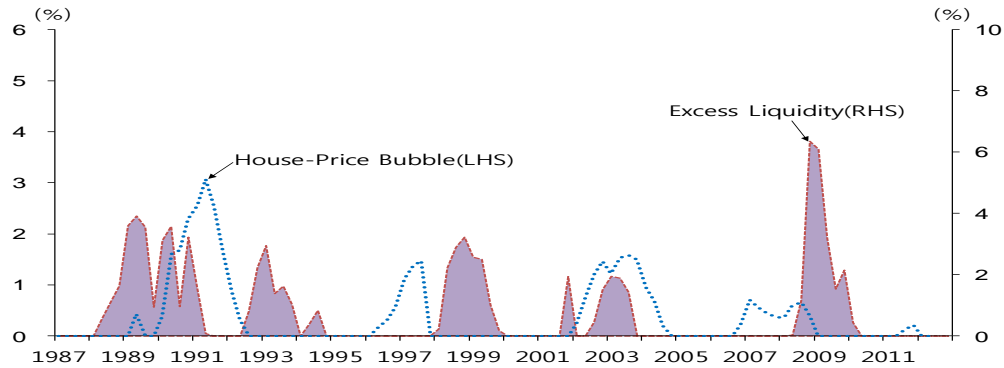
Similar to the calculation of the liquidity ratio gaps, the house-price gaps are calculated by subtracting the log values of long-term trends, obtained by the H-P filtering, from the log values of a house-price index. Note that only the “positive” values of the gap are

defined as house-price bubbles because central banks generally care more about them.¹³⁶

The bubbles are displayed in Figure 6.3, in which there are roughly four occasions when bubbles have occurred in Korea since the late 1990s like the case of excess liquidity.

Figure 6.3: Excess Liquidity and House-Price Bubbles

(X-axis in quarters)



Cross-correlation coefficients at various leads and lags up to 16 quarters are calculated in order to investigate the relationships between excess liquidity and house-price bubbles. Cross-correlations, albeit incomplete, show some dynamic relationships between variables. As reported in Table 6.1, although plus (+) signs of contemporaneous cross-correlations are in line with theoretical predictions, they are not statistically significant. However, as seen in the first column of Table 6.1, the maximum cross-correlation is achieved at a lead of four quarters, and correlation coefficients in the ranges of the fourth and fifth quarters show a statistical significance, turning negative thereafter. This implies that excess liquidity tends to lead by four or five quarters ahead of the house-price bubbles. Here, it is important to notice that the ‘minus’ ($-k$) and ‘plus’ ($+k$) signs mean ‘leads’ and ‘lags’ of excess liquidity ($X_{t\pm k}$) to house-price bubbles (Y_t), respectively.

¹³⁶ Of course, the formation of “negative” bubbles is also possible. However, such bubbles are inclined to stem from a process of collapse of positive bubbles (ECB, 2005). See also Semmler and Zhang (2007), Goodhart and Hofman (2007) for a definition and calculation of a bubble.

Interestingly, the cross-correlation analysis reveals that reverse relationships between the two variables occur, that is, house-price bubbles reversely move ahead of excess liquidity. It is evidently possible that an increase in house-related lending by financial institutions can be caused by escalating house prices and bubbles. This can be seen in the second column in Table 6.1.

Table 6.1: Cross-correlations between Excess Liquidity and House-price Bubbles
(1987:q1–2011:q4)

Quarter (k)	Excess liquidity (X_{t-k}) ²⁾ → House-price bubbles (Y_t)	House-price bubbles (Y_t) → Excess liquidity (X_{t+k}) ²⁾
0	0.036	0.036
1	0.082	-0.017
2	0.136	-0.048
3	0.190	-0.049
4	0.219 **	-0.024
5	0.215 **	0.107
6	0.181	0.200 **
7	0.160	0.210 **
8	0.127	0.180
9	0.058	0.047
10	-0.011	-0.034
11	-0.076	-0.104
12	-0.114	-0.185
13	-0.119	-0.219
14	-0.067	-0.232

Note: 1) ** indicates that cross-correlation coefficients are statistically significant at the 5% level.
The approximate critical value of the cross-correlation coefficient at the 5% two-tailed significance level is plus or minus $2/\sqrt{N}$, which is roughly 0.20, where N is the length of the series.
2) The 'minus'(- k) and 'plus'(+ k) signs mean leads and lags of excess liquidity($X_{t\pm k}$) to house-price bubbles (Y_t), respectively.

In short, the exorbitant growth of monetary aggregates may, via changes in credit or excessive liquidity, convey some useful information on house prices which matter for the stability of the real economy and the financial system in Korea. It is found that house-price bubbles were all but accompanied by excess liquidity over the period after the late 1990s.

6.3.3 Trends of House Prices and Inflation

This subsection investigates the relationship of house and land prices to

macroeconomic variables such as inflation and the GDP gap in Korea. In order to compare the relationship among asset-price movements, changes in stock prices together with real estate prices are both considered. Due to the problem of data availability (particularly, house prices), the graphical analyses are conducted for the period after the late 1980s, and quarterly data are used considering that the evolutions of changes in GDP gaps, inflation and real estate prices are calculated on a quarter-on-quarter basis.

House prices are one of the representative real estate prices in Korea. Hence, we review the trends of asset prices focusing on the effects of house prices on inflation. The inflation rate became a bit higher at the start of the 1990s but thereafter showed a general downward-trend. House and land price movements, on the whole, have shown similar patterns, while they differ in accordance with the extent of the rises and falls at different times. Figure 6.4 plots the trajectory of asset-price movements and inflation.

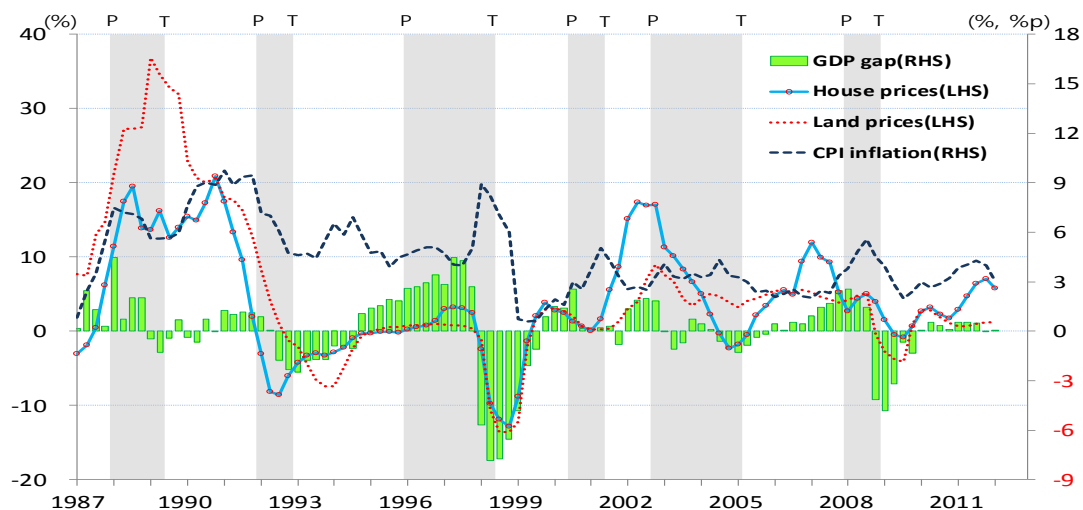
As plotted in Panel A of Figure 6.4, both house and land prices fluctuated considerably in the late 1980s when the so-called “three-lows prosperity” caused by low interest rates, low oil prices and the low dollar value resulted in excess liquidity, thereby leading to large surges in real estate prices and inflation. But they dropped sharply in the turmoil of the Korean currency crisis of 1997–1998. Since the early 2000s when the currency crisis was about to end and asset prices soared due to low interest rates, both prices again showed upward rises except for the two periods of 2003–2004 and 2007–2008¹³⁷.

¹³⁷ The first episode of downturns in house prices since 2000 is related to the economic downturn caused by the bursting of credit card bubbles in 2003. After the Korean currency crisis of 1997–1998, the government encouraged banks to issue credit cards to promote consumer spending, which resulted in the rise in the delinquency rate by over 14 percent at the end of 2003. The excessive indebtedness affected the real economy by weakening the private consumption expenditure

Their movements have varied over time: in the early 1990s, the land-price volatility showed more rapidly than that of house prices, and since the early 2000s, the volatility of house prices has been larger than that of land prices. Overall, the magnitudes of real estate price fluctuations are larger than those of inflation except for some periods of time.

Figure 6.4: Trends¹⁾ in Inflation Rate and Changes in Asset Prices (1987:q1–2011:q4)
(X-axis in quarters)

Panel A: Real Estate Prices and Inflation

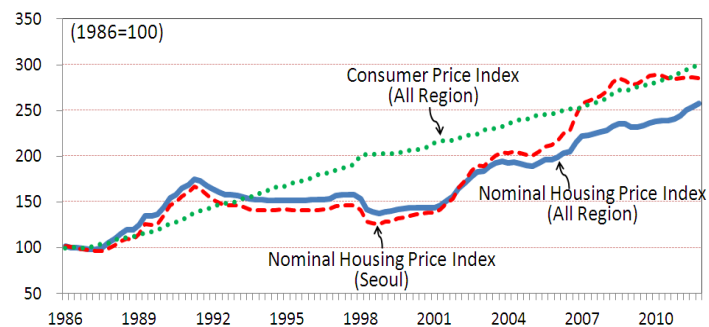


Notes: 1) All the change rates except for GDP gaps are compared with the same periods of the previous years.
2) Each of 'P' and 'T' denotes a peak and a trough in business cycles, respectively, in Korea, so that shaded areas represent economic recession periods.

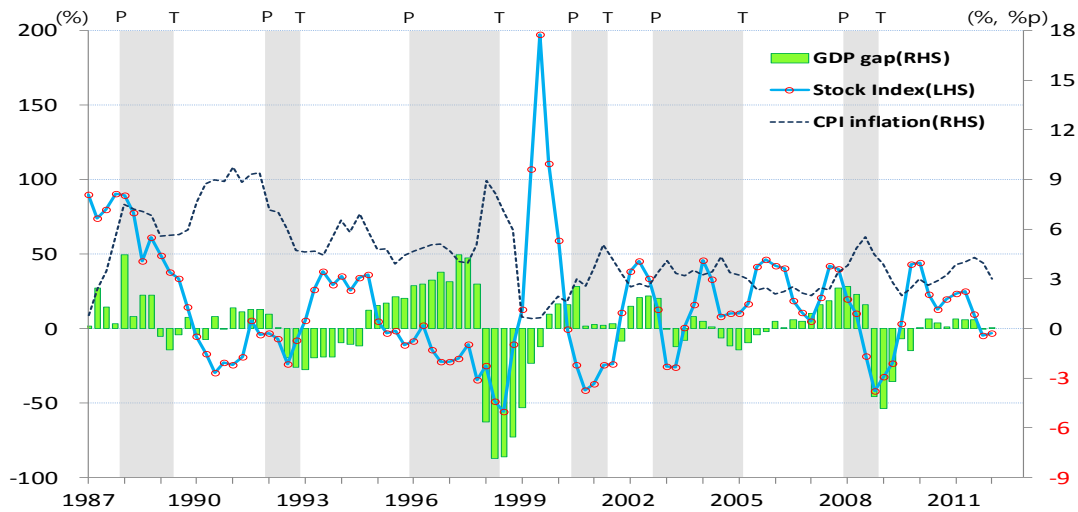
Sources: ECOS database, The Bank of Korea; Kookmin Bank Survey; The Minister of Land, Transport and Maritime Affairs.

and the housing purchases. The second is attributable to the 2007-2009 GFC that hit the world economy. Outbreak of the GFC contracted the domestic credit market which, in turn, decreased consumption, output, and house prices.

House prices in nominal terms have risen dramatically over the past 20 years. The figure in the right hand side plots the trajectory of house price and consumer price indices in Korea since 1986.



Panel B: Stock Prices and Inflation



Source: ECOS database, The Bank of Korea.

Panel B of Figure 6.4 shows the movements of stock prices and inflation since the mid 1980s. It is noticeable that stock price changes repeatedly fluctuate without showing a clear relation with the inflation rate. In 1998, the CPI inflation rapidly rose while stock prices resurged immediately after a deep plunge. Hence, the theoretical predictions that wealth effects owing to rising stock prices would stimulate consumption, and accordingly lead inflationary pressures to accelerate is not clearly proven by the figure. This means that the effect channels of stock-price increases on inflation are not singular, and that it is difficult to explain clearly the relationships between the two variables due to the other effects caused by exchange rates, economic fundamentals like unit labor cost changes, and other variables.

In order to examine how real estate prices move ahead of inflation rates, cross-correlation coefficients between house and land prices and inflation, and the GDP gap are calculated. Table 6.2 reports that house prices are positively correlated with the GDP

gap and are also positively correlated with inflation. In particular, house prices significantly lead inflation, while they are more concurrently correlated with the GDP gap than leading them. For land prices, they display more concurrent correlation with the GDP gap like house prices, and show positively strong correlations with inflation for a long time lag. Like house prices, land prices lead inflation as well. This result thereby makes it difficult for us to choose a certain lag of time. Stock prices appear to have statistically significant precedence over the GDP gap to some extent and therefore move in advance depending on predictions of future economic changes. But they do not seem to have statistically positive significant correlations with inflation. On the whole, real estate prices lead inflation while stock prices do not. This is mainly because real estate prices may be directly reflected in the price index as one of its components like rent, coupled with the high possibility that they affect prices through various channels such as wealth effects, cost channels associated with wages or rent, and inflation expectations.

Table 6.2: Dynamic Correlations¹⁾ among Asset-price Changes and Inflation
(1987:q1-2011:q4)

$X_{t \pm k}$	Y_t	$k = -6$	-5	-4	-3	-2	-1	0	$k = 1$	2	3	4	5	6
House prices	GDP gap	-0.14	-0.05	0.04	0.16	0.28	0.39	0.44	0.43	0.33	0.18	0.06	-0.01	-0.04
	Inflation	0.37	0.41	0.43	0.41	0.35	0.28	0.18	0.06	-0.02	-0.10	-0.14	-0.17	-0.22
Land prices	GDP gap	-0.08	-0.04	0.01	0.09	0.18	0.27	0.35	0.38	0.33	0.23	0.14	0.05	0.01
	Inflation	0.60	0.61	0.60	0.58	0.53	0.47	0.38	0.28	0.22	0.18	0.16	0.13	0.07
Stock prices	GDP gap	0.12	0.13	0.22	0.26	0.31	0.32	0.18	-0.03	-0.30	-0.51	-0.60	-0.52	-0.29
	Inflation	0.13	0.09	0.04	-0.03	-0.13	-0.26	-0.37	-0.41	-0.33	-0.13	0.03	0.13	0.12

Notes: 1) measured by cross-correlation coefficients between the GDP gap and CPI inflation at time t and percent changes in prices of house, land and stock assets at time $t \pm k$, respectively.

2) The numbers in shaded areas indicate that correlation coefficients are statistically significant at the 5% level. The approximate critical value of the cross-correlation coefficient at the 5% two-tailed significance level is a plus or minus $2/\sqrt{N}$, which is roughly 0.2, where N is the length of the data series (*i.e.*, $N=100$).

Sources: Kookmin Bank Survey; and The Minister of Land, Transport and Maritime Affairs.

6.4 The Model

In what follows, we introduce the *basic* New Keynesian (NK) model presented in the existing literature. This is followed by the discussions on the theoretical framework of a hybrid version of the NK model. And then, we show the state-space representation of the baseline model and explain the model solution method. In addition, we discuss the optimal control problem focusing mainly on the central bank's objective function which will be used to compare the central bank's responses. Finally, we will discuss the structure and feature of the alternative model which is of great importance in contrast to the baseline model.

6.4.1 The *Basic* New Keynesian Framework

The *basic* New Keynesian (NK) model introduced herein is taken from existing papers, for example, in Clarida *et. al.* (1999 and 2000), Woodford (2003a,b), and Giordani and Söderlind (2004). The *basic* NK model can be derived as log-linear approximations to equilibrium conditions of an underlying dynamic general equilibrium model with price stickiness¹³⁸. While the model is very simple, it incorporates forward-looking private-sector behaviour in three respects: households and firms' optimisation; rational expectations; and nominal price rigidity. In that sense, the NK model is a kind of “miniature” of the dynamic stochastic general equilibrium (DSGE) models. Appendix A shows explicit derivations of the *basic* NK model.¹³⁹ The model's two key equations are the forward-looking New Keynesian Phillips curve (henceforth, ‘NKPC’) of the form:

¹³⁸ See Chapter 4 in Woodford (2003b).

¹³⁹ See also the textbooks by Woodford (2003a), Galí (2008) and Walsh (2010) and a paper by Galí and Gertler (2007), for a deeper discussion of the NK model, including the derivation of the first two equations. On the empirical sides, the majority of the existing literature focuses on the NKPC. However, there are also some studies on the optimising IS curve, for example, Fuhrer (2000) and Kara and Nelson (2004), among others.

$$\pi_t = \delta E_t \pi_{t+1} + \kappa y_t, \quad (6.1)$$

and the dynamic IS curve (or ‘DISC’ for short, following Galí (2008)) of the form:

$$y_t = E_t y_{t+1} - \gamma^{-1} (i_t - E_t \pi_{t+1} - r_t^n), \quad (6.2)$$

where π_t stands for the inflation rate at time t , y_t denotes the output gap, defined as actual output relative to the equilibrium level of output under flexible prices, and i_t is the short-term nominal interest rate controlled by the central bank. All three variables represent percentage deviations around their steady-state values. The last term r_t^n is the natural interest rate, defined as the equilibrium real rate of interest that equates actual output to its natural level.¹⁴⁰ E_t denotes the rational expectations operator given the private sector information set at time t which contains π_t , y_t , i_t and all the lags of these variables. The first Equation (6.1), the NKPC, describes the short-run dynamics of inflation arising from the process of wage-setting between firms and workers,¹⁴¹ while the second Equation (6.2) relates household spending decisions to the interest rate.

As seen in Appendix A, the *basic* NKPC is a log-linear approximation to the first-order condition for the optimal price-setting decisions by the representative supplier, combined with an equation relating marginal cost to real activity (Galí, 2008; Chapter

¹⁴⁰ Note that the equilibrium real rate of interest is achieved when there is no nominal rigidity (Montoro, 2007).

¹⁴¹ This curve implies that current inflation is affected by two components: one is expected future inflation that enters the curve to reflect price rigidity. The other is the marginal cost which enters due to monopolistic competition. This condition is captured by the output gap term which acts as a proxy for labour-market conditions affecting wages and thereby marginal cost.

3). This curve is often interpreted as an aggregate supply (AS) equation.¹⁴² The second equation of the NK model is the “optimising” IS curve or the *basic* DISC, (6.2), which is often called an aggregate demand (AD) equation. The *basic* DISC can be interpreted as a log-linear approximation to the representative household’s Euler equation for optimal consumption decisions.

The parameters, κ and γ , are both non-negative by assumption. The former, κ , which is the slope of (the short-run) Phillips curve, depends on the primitive parameters of the model, particularly the parameter that determines the average frequency of price changes¹⁴³ and on the elasticity of demand that goods suppliers face. This parameter can be seen in Equation (A.35) in Appendix A and Equation (B.10) in Appendix B. Next, the latter, γ is the inverse of the intertemporal elasticity of substitution. The parameter γ^{-1} acts as the slope of the *basic* DISC. Finally, $\delta \in (0,1]$ denotes the time discount factor of the price-setters, which is assumed to be the same as the discount factor of the representative household. In addition to the above two non-policy equations, in order to close the model, we need a block describing how monetary policy is conducted. The simplest possible monetary policy rule is given by a version of the so-called Taylor rule such as:

$$i_t = \phi_\pi \pi_t + \phi_y y_t + v_t, \quad (6.3)$$

where i_t is the short-term nominal interest, and v_t is an exogenous component with zero

¹⁴² Notice that the *basic* NKPC or the AS curve is a generalisation of the supply specification originally introduced by Calvo (1983) assuming the presence of staggered nominal price-setting, and later more developed by, for instance, Fuhrer and Moore (1995) employing the overlapping wage contracting model in which relative real wages are regarded as important.

¹⁴³ In other words, the slope of the Phillips curve represents a measure of the speed of price adjustment.

mean. We further assume ϕ_π and ϕ_y are non-negative coefficients, chosen by the central bank.

6.4.2 The Baseline Model: a Hybrid version of the NK Model

The baseline model is a variant of the *basic* forward-looking models discussed above. The model is composed of three key structural relationships: the Phillips curve, the dynamic IS curve and the monetary policy rule equation. The first two equations constitute the non-policy block of the hybrid NK model. The last equation describes central banks' decision-making behaviour, which closes the NK model.

Each of the equations includes a forward-looking part, and a lagged variable to reflect endogenous persistence of respective variables, which makes it possible to capture persistent dynamics in the economic activity. It is important to note that model descriptions will be based on the NK approach which stresses the importance of forward-looking expectations by economic agents. In addition, it is worth mentioning that there is no asymmetric information between economic agents (firms and households) and the central bank. Here, the baseline model is assumed to represent a flexible IT regime, mainly pursuing price stability. The three key equations will be explained in more detail as follows.

6.4.2.1 The Hybrid Phillips Curve

We assume that current inflation, π_t is determined by three components: private-sector's time $t + 1$ inflation expectations, $E_t\pi_{t+1}$ conditional on the time t information set; past inflation, π_{t-1} ; and the current output gap, y_t . Here, it is important to note that the inclusion of the lagged term, π_{t-1} into the *basic* NKPC is to capture inflation persistence

which is apparent in the actual data. This variant is referred to as a so-called ‘*hybrid* NKPC’, which takes the form:

$$\pi_t = \alpha_\pi \hat{\delta} E_t \pi_{t+1} + (1 - \alpha_\pi) \pi_{t-1} + \alpha_y y_t + u_t, \quad (6.4)$$

Appendix B.1 shows derivations of the hybrid NKPC.¹⁴⁴ In Equation (6.4), the parameters, α_π and α_y , are assumed to be positive. From a microeconomic foundation view, the parameter $\hat{\delta}$ represents the factor with which goods suppliers discount future real income, and the latter, α_y is the slope of the Phillips curve, depending on the average frequency of price changes and the elasticity of demand that suppliers face.¹⁴⁵ In the simple case which excludes the output gap (y_t) in Equation (6.4), *i.e.*, $\alpha_y = 0$, it implies that inflation is affected by expected future inflation, $E_t \pi_{t+1}$ and by past inflation, π_{t-1} with weights α_π and $1 - \alpha_\pi$, respectively.

In Equation (6.4), the disturbance term, u_t represents an aggregate supply structural shock, assumed to be independently and identically distributed (*i.i.d.*) with zero mean and homoskedastic variance, σ_u^2 . As in, for instance, Clarida *et al.* (1999), it can be interpreted as a cost-push shock captured by a first-order autoregression – or an AR(1) process:

$$u_t = \rho_u u_{t-1} + \varepsilon_t, \text{ where } \rho_u \in [0,1) \text{ and } \varepsilon_t \text{ is } i.i.d. \text{ N}(0, \sigma_\varepsilon^2). \quad (6.5)$$

¹⁴⁴ See, also the discussions in, particularly, Galí and Gertler (1999), Fuhrer (2000), Steinsson (2003) and Rudd and Whelan (2006) for the derivation of the hybrid version of the NKPC.

¹⁴⁵ In Equation (6.3), the parameter, $\alpha_\pi \hat{\delta}$ corresponds to the subjective discount factor of the representative suppliers, δ satisfying $0 < \delta < 1$, and α_y corresponds to κ , *i.e.*, $(1 - \theta)(1 - \theta\delta)\theta^{-1}(\gamma + \gamma_n)$ which both appear in the original version of expectations-augmented Phillips curve, *i.e.*, $\pi_t = \delta E_t \pi_{t+1} + \kappa y_t$, which is often referred to as the ‘*basic*’ *New Keynesian Phillips Curve* (NKPC). See more explanations in Clarida *et al.* (1999) and Walsh (2003 and 2010).

6.4.2.2 The Hybrid Dynamic IS Curve

Again, it is assumed that the current output gap, y_t depends on the expectations as to the future output gap based on the information set at time t , $E_t y_{t+1}$, the past output gap, y_{t-1} , and *real* interest rates, $i_t - E_t \pi_{t+1}$, where i_t is a short-term *nominal* interest rate. Similar to the NKPC, note that the lagged term of the output gap is added to the *basic* DISC in order to capture the output gap persistence existing in the actual data. Let us call this modified curve a ‘*hybrid* DISC, yielding the form:

$$y_t = \beta_y E_t y_{t+1} + (1 - \beta_y) y_{t-1} - \beta_i (i_t - E_t \pi_{t+1}) + v_t, \quad (6.6)$$

Appendix B.2 shows derivations of the hybrid DISC. In Equation (6.6), y_t is the output gap at time t , the parameters β_y and β_i are both assumed to be non-negative. In particular, β_i corresponds to the slope of the *basic* IS curve, γ^{-1} . It is important to know that the IS curve relates the output gap inversely to the *ex-ante* real interest rate, which represents the monetary policy transmission channel in the IS curve. And, it is worth noting that Equation (6.6) will be slightly modified to reflect the simplicity of transmission mechanism of interest rates to house prices and to ultimately aggregate demand, already discussed in Figure 6.1 plotted in Section 6.2.

The disturbance term, v_t in Equation (6.6), is an exogenous demand shock¹⁴⁶, assumed to be *i.i.d.* with zero mean and homoskedastic variance, σ_v^2 . It also obeys the stationary AR(1) process:

¹⁴⁶ It is useful to know that the exogenous shock v_t contains $\beta_i r_t^n$ for simplicity of the equation.

$$v_t = \rho_v v_{t-1} + \eta_t, \text{ where } \rho_v \in [0,1) \text{ and } \eta_t \text{ is i.i.d. } N(0, \sigma_\eta^2). \quad (6.7)$$

6.4.2.3 The Monetary Policy Reaction Function

In order to close the NK model as stated earlier, we consider the equation describing how monetary policy is implemented. Such an equation is called a monetary policy rule in which the short-term nominal interest rate is the central bank's policy instrument. It is assumed that the central bank conducts the monetary policy according to the Taylor-rule type forward-looking reaction function of the form¹⁴⁷:

$$i_t = \rho i_{t-1} + (1 - \rho)(\phi_\pi E_t \pi_{t+1} + \phi_y y_t) + e_t, \quad (6.8)$$

where the disturbance term, e_t is a zero-mean exogenous shock, assumed to be independently and identically distributed with homoskedastic variance, σ_e^2 . As discussed in Chapters 4 and 5, the central bank facing uncertainty shows a tendency to move the key policy rate gradually. This tendency is called “interest-rate smoothing”. This feature can be incorporated in the monetary policy rule by including a partial adjustment term, placing a weight of ρ on the past values of policy interest rate, i_{t-1} . The parameter, ρ , measures the degree of interest-rate smoothing by the central bank. Regarding the presence of an interest-rate smoothing component, many authors, for example, Clarida *et*

¹⁴⁷ Since all variables are expressed as log-deviations from their steady-state values, a constant term was delted. In Equation (6.8), if there is a constant term c_i and when $c_i = (1 - \rho)(\bar{i} - \phi_\pi \pi^T)$, this reaction function can be divided into two parts: $i_t = \rho i_{t-1} + (1 - \rho)i_t^* + e_t$ and $i_t^* = \bar{i} + \phi_\pi (E_t \pi_{t+1} - \pi^T) + \phi_y y_t$, where i_t and i_t^* are the actual policy instrument rate and the policy target rate, respectively. In the first equation, the lagged policy interest rate, i_{t-1} , is included to capture the tendency of the central bank to smooth interest-rate adjustments; whereas i_t^* represents a forward-looking version of the simple Taylor rule whereby the central bank responds to deviations of expected inflation from the inflation target and to the current output gap as formulated in the second equation. See the discussion in Woodford (1999).

al. (1999 and 2000), Sahuc (2002) and Orphanides (2004), have pointed out that the above form of monetary policy rule best captures the actual data. Both ϕ_π and ϕ_y are positive parameters, chosen by the central bank: ϕ_π measures the degree of response of the central bank to the *expected* inflation; whereas ϕ_y gauges its reaction to the *current* output gap. Therefore, Equation (6.8) implies that the central bank responds to the past nominal rate of interest, expected future inflation and the current output gap, where the first two variables are used to justify the existence of possible monetary policy transmission delays to the economy. And it is assumed that the exogenous structural shock, e_t , follows an AR(1) process:

$$e_t = \rho_e e_{t-1} + \mu_t, \text{ where } \rho_e \in [0,1) \text{ and } \mu_t \text{ is i.i.d. } N(0, \sigma_\mu^2). \quad (6.9)$$

Here, it is worth noting that given inflation and the output gap, a *positive* realisation of e_t can be interpreted as a contractionary monetary policy shock, leading to a rise in the nominal interest rate, and *vice versa* for a negative case.

6.4.3 The State-space Formulation of the Model and its Solution

Equations (6.4) to (6.9), describing the key aggregate relationships of the economy based on the spirit of the New Keynesian approach form a system of difference equations that can be solved recursively. This section derives the linear rational expectations solution of the model. In order to solve the model numerically, we follow the standard solution algorithms for the linearised approximate model described in Sims (2002).

Let us define a (8×1) vector of endogenous variables as:

$$X_t = [u_t, v_t, e_t, i_t, y_t, \pi_t, E_t y_{t+1}, E_t \pi_{t+1}]', \quad (6.10)$$

a (8×1) vector of variables contains the predetermined variables u_{t-1} , v_{t-1} , e_{t-1} , i_{t-1} , y_{t-1} and π_{t-1} , and the forward-looking variables at time $t-1$, $E_{t-1}y_t$ and $E_{t-1}\pi_t$:

$$X_{t-1} = [u_{t-1}, v_{t-1}, e_{t-1}, i_{t-1}, y_{t-1}, \pi_{t-1}, E_{t-1}y_t, E_{t-1}\pi_t]', \quad (6.11)$$

a (3×1) vector collecting the exogenous structural shocks for the predetermined variables, i_{t-1} , y_{t-1} and π_{t-1} :

$$z_t = [\varepsilon_t, \eta_t, \mu_t]', \quad (6.12)$$

and a (2×1) vector of endogenous forecast errors, fulfilling $E_{t-1}\zeta_t = 0$ for all t :

$$\zeta_t = [\zeta_t^y, \zeta_t^\pi]' \quad (6.13)$$

where $\zeta_t^y = y_t - E_{t-1}y_t$ and $\zeta_t^\pi = \pi_t - E_{t-1}\pi_t$.

Recall that we assume rational expectations and no informational difference between the private-sector and the central bank. Hence, combining Equations (6.4)–(6.9), we have a system of difference equations, which can be written in state-space form as:

$$\Gamma_0 X_t = C + \Gamma_1 X_{t-1} + \Psi z_t + \Pi \zeta_t. \quad (6.14)$$

where Γ_0 , Γ_1 , Ψ and Π are matrices conformable to X_t , X_{t-1} , z_t and ζ_t which are explained above.

In this system, the (8×8) coefficient matrices Γ_0 and Γ_1 , a vector of constants C , the (8×3) matrix Ψ , and the (8×2) matrix Π are respectively given by:

$$C = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}, \quad \Gamma_0 = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -1 & 1 & -(1-\rho)\phi_y & 0 & 0 & -(1-\rho)\phi_\pi \\ 0 & -1 & 0 & \beta_i & 1 & 0 & -\beta_y & -\beta_i \\ -1 & 0 & 0 & 0 & -\alpha_y & 1 & 0 & -\alpha_\pi \hat{\delta} \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \end{bmatrix},$$

$$\Gamma_1 = \begin{bmatrix} \rho_u & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \rho_v & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \rho_e & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \rho & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & (1-\beta_y) & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & (1-\alpha_\pi) & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}, \quad \Psi = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}, \quad \text{and} \quad \Pi = \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 1 & 0 \\ 0 & 1 \end{bmatrix}.$$

The system can be expressed in a standard state-space form as follows:

$$X_t = \Phi + MX_{t-1} + \Xi z_t + \Theta \zeta_t. \quad (6.15)$$

where $\Phi = \Gamma_0^{-1}C$, $M = \Gamma_0^{-1}\Gamma_1$, $\Xi = \Gamma_0^{-1}\Psi$ and $\Theta = \Gamma_0^{-1}\Pi$.

The model can be solved using the methods suggested by Sims (2002). It can then be estimated using the Kalman filter.

6.4.4 The Central Bank's Objective Function

In general, the optimal control model for analysing the effectiveness of monetary policies with different objectives is composed of the objective function of the policy authority and economic system equations that work as a constraint to the optimisation problem.

We know that the optimal control framework has *two* useful features for policy analysis. One is that it deals with the existence of ‘uncertainty’ as indicated by the terminology ‘expected’. Since monetary policy works under variable lags, this framework is essential for a realistic description of the central bank’s problem. The underlying assumption for this is that policymakers are faced with so-called Bayesian uncertainty, *i.e.*, even if they *do not* know the exact realisation of future shock, they *do* know the characteristics of the probability distribution from which this shock is drawn. The other is that as already discussed in Chapter 2, if this shock enters the model additively and if the central bank’s objective function takes a quadratic form, the model will display the convenient characteristic of ‘certainty equivalence’. Alternatively, the model may display multiplicative uncertainty, in which case policymakers are uncertain about the impact of their actions on ultimate goal variables.

Following the prior literature (most prominently Clarida *et al.*, 1999), we assume that the central bank seeks to minimise the discounted sum of expected future loss given by:

$$\min_{\{i\}} E_t \sum_{k=0}^{\infty} \delta^k L_{t+k}, \quad (6.16)$$

subject to the constraints implied by (6.4) and (6.6) describing the structure of the economy, where $\delta \in (0,1]$ is the discount factor mentioned earlier, and the period loss

function takes the form¹⁴⁸:

$$L_t = \frac{1}{2}[(\pi_t - \pi^T)^2 + \lambda y_t^2 + \nu i_t^2] \quad (6.17)$$

where the parameters $\lambda \geq 0$ and $\nu \geq 0$ are the relative weights placed on the output gap stabilisation and interest rate stability, respectively with respect to inflation stabilisation, and π_t , y_t and i_t are the goal variables. This loss function penalises deviations of inflation from its target, π^T , and variations in the output gap and the level of nominal interest rates. Therefore, Equation (6.17) is a case that can be called as a standard flexible IT regime. In the loss function, expectations are conditional on the economy's state at the time when alternative policies are to be evaluated, and assumed to occur earlier than the realisation of the exogenous economic shocks at time 0 . This is a rather conventional loss function with the last term of the interest-rate stabilisation objective.¹⁴⁹ The expected value of the period loss function (6.17) can be expressed conveniently in terms of the variances that appear in the loss function. Such an expression may be useful in linking the gap between theoretical and empirical analyses where the variance is a general statistic for measuring the magnitude of fluctuations of price or quantity variables. The transformations of two loss functions are shown as below.

Suppose that policy horizons of the central bank are limited to only the current period. Then we can show easily that the intertemporal loss function turns to the period

¹⁴⁸ Woodford (1999 and 2003a) shows that a quadratic loss function like (6.17) can be obtained by a second-order Taylor approximation to the expected utility of the representative household in the model that has been used to derive the New Keynesian Phillips curve and the intertemporal IS curve discussed in Appendix A..

¹⁴⁹ Friedman (1969) argues that high nominal interest rates lead welfare costs of transactions to rise. Moreover, Woodford (1990 and 1999a) states that it may be desirable to lower their variability as well as the level of nominal interest rates. See Chapter 6 in Woodford (2003a) for a more theoretical justification for this objective function, in the context of microeconomic foundations of the structural model behind Equations (6.4) and (6.6).

loss function (6.17). As the target for the inflation rate is *time-invariant*, the unconditional expectation of the evolution of the inflation rate reduces to $E[\pi_t] = \pi^T$. The target for the output gap, y^T is 0 since the central bank seeks to keep the *actual* level of real output, x_t^a at its *potential* level, x_t^p , i.e., $E[y_t] = y^T = x_t^a - x_t^p = 0$. Similarly, the target for the interest rate gap, i^T is 0, i.e., $E[i_t] = i^T = ir_t^a - ir_t^n = 0$, where ir_t^a and ir_t^n are the *actual* nominal interest rate and its *natural* rate of interest, respectively.

With regard to the equality of the unconditional expectation with the three target variables, the period loss function can be rewritten as:

$$L_t = (\pi_t - E[\pi_t])^2 + \lambda(y_t - E[y_t])^2 + \nu(i_t - E[i_t])^2. \quad (6.18)$$

Equation (6.18) reflects the fact that uncertainty features in the policy process even in the one-period case. After all, the central bank aims to minimise the expected one-period loss function, that is, the average loss which corresponds to the sum of the mean squared error (MSE) of the inflation rate, the output gap and interest rate. Therefore, we have:

$$E[L_t] = E(\pi_t - E[\pi_t])^2 + \lambda E(y_t - E[y_t])^2 + \nu E(i_t - E[i_t])^2. \quad (6.19)$$

Or more succinctly, we obtain:

$$E[L_t] = \text{Var}[\pi_t] + \lambda \text{Var}[y_t] + \nu \text{Var}[i_t]. \quad (6.20)$$

where $\text{Var}[X_t]$ stands for the variance of variable X_t . Equation (6.20) implies that the unconditional mean of the period loss function equals the weighted sum of the unconditional variances of the inflation rate, the output gap and interest rate.

The expected value of the *intertemporal* loss function also reduces to the weighted sum of the unconditional variances of the goal variables. However, in order to obtain this result, a slight modification of the loss function and subsequently taking a mathematical limit are required. The first step of the transformation of the intertemporal loss function is to scale Equation (6.16) by $(1 - \delta)$:

$$(1 - \delta)E_t \sum_{k=0}^{\infty} \delta^k \{(\pi_t - \pi^T)^2 + \lambda y_t^2 + v_t^2\}. \quad (6.21)$$

The second step involves taking the limit of the above equation as the discount factor $\delta \rightarrow 1$. More formally expressing Equation (6.21) yields:

$$\lim_{\delta \rightarrow 1} (1 - \delta)E_t \sum_{k=0}^{\infty} \delta^k \{(\pi_t - \pi^T)^2 + \lambda y_t^2 + v_t^2\}. \quad (6.22)$$

Evaluating this expression enables us to restate the scaled loss function as the weighted sum of the unconditional variances of the inflation gap, the output gap and interest rate. Here, as $\delta \rightarrow 1$, the value of the intertemporal loss function approaches the infinite sum of the unconditional mean of the period loss function, $E[L_t]$.¹⁵⁰ As explained in Rudebusch and Svensson (1999), Rudebusch (2005), among others, we can also define the optimisation problem for $\delta=1$ and then simply interpret the intertemporal loss function as the unconditional *mean* of the period loss function, which is the same as the weighted sum of the unconditional variances of the goal variables mentioned above. For convenience, the equation is repeated here as:

¹⁵⁰ See a more detailed discussion in Froyen and Guender (2007).

$$E[L_t] = Var[\pi_t] + \lambda Var[y_t] + \nu Var[i_t]. \quad (6.20)$$

This expression will serve as the welfare criterion for assessing the effectiveness of monetary policy strategies in this chapter.

6.4.5 The Alternative Model

The alternative model is composed of four equations: the Phillips curve; the IS curve; the house price equation and the policy rule equation. Following Cardani (2008) and Airaudo *et al.* (2013)¹⁵¹, the house-price determination equation is included to represent financial stability regarding house prices. As can be seen below, the first two equations and the policy rule equation are basically identical to those in the baseline model in terms of their respective structures, except that the variable, q_t , denoting the house price inflation gap, is included in the IS curve, Equation (6.6)', and in the policy rule, Equation (6.8)'. In particular, a slightly modified version of the IS curve implies that changes in house prices affect the aggregate demand with a lag through wealth effects (*i.e.*, $q_{t-1} \rightarrow y_t$). And, following the existing literature¹⁵², we establish the alternative policy rule, Equation (6.8)' in which the central bank also reacts to the changes in house prices, which will be discussed later in more detail.

The alternative model, which consists of four structural equations and corresponding shocks is given by:

¹⁵¹ They considered an economy where asset prices affect the real economy through aggregate demand, introducing an asset pricing equation as a *third* equation. But, he assumes that stock prices instead of house prices perturb the aggregate demand in the model.

¹⁵² See, for example, Semmler and Zhang (2007), Bauducco *et al.* (2008), and Kannan *et al.* (2009).

$$[\text{The Phillips Curve}] \quad \pi_t = \alpha_\pi \hat{\delta} E_t \pi_{t+1} + (1 - \alpha_\pi) \pi_{t-1} + \alpha_y y_t + u_t \quad (6.4)'$$

$$u_t = \rho_u u_{t-1} + \varepsilon_t \quad (6.5)'$$

$$[\text{The IS Curve}] \quad y_t = \beta_y E_t y_{t+1} + (1 - \beta_y) y_{t-1} - \beta_i (i_t - E_t \pi_{t+1}) + \beta_q q_{t-1} + v_t \quad (6.6)'$$

$$v_t = \rho_v v_{t-1} + \eta_t \quad (6.7)'$$

$$[\text{The House Price Equation}] \quad q_t = \gamma_q E_t q_{t+1} + (1 - \gamma_q) q_{t-1} - \gamma_i (i_t - E_t \pi_{t+1}) + w_t \quad (6.23)$$

$$w_t = \rho_w w_{t-1} + \varpi_t \quad (6.24)$$

$$[\text{The Policy Rule 2}] \quad i_t = \rho_i i_{t-1} + (1 - \rho) (\phi_\pi E_t \pi_{t+1} + \phi_y y_t + \phi_q q_t) + e_t \quad (6.8)'$$

$$e_t = \rho_e e_{t-1} + \mu_t \quad (6.9)'$$

The notation is the same as in the baseline model. But, some explanation of the house price gap effect needs to be added: house prices, q_t , are expressed as a gap which is obtained by the difference between house price inflation rate and its detrended rate. In Equation (6.23), the parameters γ_q and γ_i are assumed to be non-negative. Equation (6.23) implies that house prices depend on the expectations of the future house prices, the past house prices, and the real interest rate, $i_t - E_t \pi_{t+1}$. This relationship is a key assumption in the alternative model: house prices do not depend on either the output gap or the inflation gap. But, this assumption can be justified in that house price inflation leads CPI inflation and shows a comovement with or precedence to the output gap in Korea, as already discussed in the last part of Section 6.4. And, it is important to note that Equation (6.23) relates the house prices inversely to the *ex-ante* real interest rate. The real interest rates have an impact on house prices without a lag, and house prices have an impact on the output gap with a lag. This sequential transmission

channel was discussed in Figure 6.1 in Section 6.2.

In particular, it is assumed that changes in house prices have an impact on aggregate demand, and ultimately on inflation through the transmission channels such as *wealth effects* and *balance-sheet effects*. This can justify why we include house prices in the IS curve. As already discussed in Subsection 6.2.2, a rise in house prices tends to create an increase in wealth for households, so that they consume more since they feel richer, and *vice versa* for a fall in house prices (*wealth effects*). In addition, as summarised in Figure 6.1 in Section 6.2, rising asset prices result in increases in collateral values that companies and households can provide when they borrow for investment and consumption. This makes it easier for them to borrow, or to borrow at lower cost (*balance-sheet channels*). These two effects bring about an increase in aggregate demand (IMF, 2008).

Unlike the monetary policy rule in Equation (6.8), the central bank is now assumed to react to house-price fluctuations as seen in modified policy rules, (6.8)' – which may be termed an “*augmented* Taylor-type rule” – in which ϕ_q is accordingly expected to be positive. Recently, literature has often considered the policy rules with such variables as asset prices (Chadha *et al.*, 2004; Semmler and Zhang, 2007; Kang and Chang, 2011) and the growth rate of nominal credit (Kannan *et al.*, 2009), in addition to inflation rate and the output gap. For convenience, let us refer to the augmented Taylor-type rule in the alternative model as ‘Policy Rule 2’, while the standard Taylor-type rule in the baseline model as ‘The Policy Rule 1’.

The structural equations above are accompanied by four exogenous structural shocks $\{u_t, v_t, w_t, e_t\}$ which are all assumed to be independently and identically

distributed with zero mean and respective homoskedastic variances, and obey AR(1) processes.

Now, assume that the central bank conducts the monetary policy to minimise the loss function subject to the constraints expressed by the economic structural models. And suppose that when setting the interest rate, the central bank cares about the financial stability, therefore responding to fluctuations in house prices. In the small DSGE model, two kinds of policy reaction functions are considered: the conventional rule (The Policy Rule 1) in which the central bank does not react to house-price inflation; and the variant rule (The Policy Rule 2) in which the central bank directly reacts to house-price movements for the purpose of attaining financial stability. We want to see how the policy effect varies in the case where a house price variable is contained in the policy rule. By computing the respective loss values under two types of policy rules, we can investigate which policy position has a better outcome. For convenience, the two policy rules are rewritten as below:

$$\text{(The Policy Rule 1)} \quad i_t = \rho_1 i_{t-1} + (1 - \rho_1)(\phi_{\pi 1} E_t \pi_{t+1} + \phi_{y1} y_t) + e_{t1}$$

$$\text{(The Policy Rule 2)} \quad i_t = \rho_2 i_{t-1} + (1 - \rho_2)(\phi_{\pi 2} E_t \pi_{t+1} + \phi_{y2} y_t + \phi_q q_t) + e_{t2}$$

6.5 Analysis Results

This section presents a brief explanation about estimation methods of structural parameters, policy reaction parameters and autoregressive parameters governing the structural shocks. Next, the prior distributions of those parameters are specified, and the main estimation results are reported. Finally, we compare the quantitative results regarding the response coefficients and loss values, and then we conduct the impulse response analysis.

6.5.1 Estimation Methodology

The models are estimated using Bayesian methods that have become a standard workhorse in analysing the NK models (Luoto, 2009). The reasons why we adopt Bayesian methods are as follows: firstly, the Bayesian approach easily allows for incorporating prior beliefs about the parameters which facilitate numerical maximisation; secondly, it is easy to implement and requires less time in posterior simulation than other approaches¹⁵³. The Bayesian approach gives estimates of the structural parameters, including policy reaction parameters and the discount factor. The Metropolis-Hastings algorithm is applied for obtaining the posterior distribution of the parameters under the baseline and alternative models, respectively, where the latter model is divided into the case without caring about house-price fluctuations, and the case with considering them when the central bank decides policy interest rates. The posterior parameters can then be used to calculate any posterior function of the parameters: moments, impulse response functions, etc.

Five quarterly macro data series for Korea, which are all demeaned, are used in the estimation: inflation; the output gap; house prices; and the short-term nominal interest rate from 1999:q2 to 2011:q4.

6.5.2 Prior Distribution of the Parameters

The prior distributions, means and standard errors of the parameters in the models are

¹⁵³ Bayesian estimation methods allow us to formalise the use of prior information coming from either microeconomic or previous macroeconomic studies and thereby provide an explicit link with the previous calibration-based literature. Besides, from a practical perspective, it is known that the use of prior distributions over the structural parameters makes the highly nonlinear optimisation algorithm more stable. See, for example, Smets and Wouters (2003) and An and Schorfheide (2007) for a more detailed discussion.

listed in the first three columns of Tables 6.3~6.5. The value of discount factor, δ , is pre-set at 0.987, which implies a quarterly discount rate of around 1 percent. The slope coefficient in the Phillips curve, α_y , is assumed to be distributed as a gamma around a mean of 0.15 and a standard error of 0.01. The mean is the value corresponding to that in other studies in the literature¹⁵⁴. The value of the slope parameter in the IS curve, β_i , is also gamma distributed with a mean of 0.05 and a standard error of 0.01. As pointed out by Luoto (2009), the priors on standard errors of slope parameters $\{\alpha_y, \beta_i\}$ are set to be small enough to keep the posterior distribution away from economically non-meaningful values. The prior distribution of the parameters $\{\alpha_\pi, \beta_y\}$ for expected variables of the Phillips curve and the IS curve is beta distributed with a mean of 0.5 and a standard error of 0.2. We set a relatively large but not a unity value on these parameters to take into account the existence of considerable persistence in lagged variables.¹⁵⁵ The prior means of the policy reaction parameters ϕ_π (1.5) and ϕ_y (0.5) are chosen based on Taylor (1993).¹⁵⁶ One prior that we give special attention to is the parameter that captures the degree of smoothing in the monetary policy reaction function, ρ , which is set at 0.8, and assumed to follow a gamma distribution with a standard error of 0.2. This prior is fairly standard in that the interest-rate smoothing term in the policy reaction equation tends to show a high persistence. The distribution

¹⁵⁴ See, for example, Rudebusch (2002a,b), Orphanides and Williams (2002).

¹⁵⁵ In the conventional forward-looking NK model, the coefficient value of $E_t y_{t+1}$ is equal to one, and the coefficient of $E_t \pi_{t+1}$ is close to one. (see, for example, Clarida *et al.*, 1999; Giannoni, 2002)

¹⁵⁶ A high long-term coefficient on inflation gap allows us to have a unique solution path when estimating the model (Smets and Wouters, 2003).

of autoregressive parameters in the shock processes $\{ \rho_u, \rho_v, \rho_w \text{ and } \rho_e \}$ is assumed to follow a normal distribution with a mean of 0.6 and a standard error of 0.1. Here, the application of a rather strict standard error is for a clear separation between the persistent and non-persistent shocks as in Smets and Wouters (2003). All standard deviations of shocks $\{ \sigma_u, \sigma_v, \sigma_w \text{ and } \sigma_e \}$ are assumed to follow inverse-gamma distribution with means of 0.5 and standard errors of 0.02. This distribution guarantees positive standard deviations with a large domain.

Turning to the parameters for the alternative model, the prior distribution of the parameter (β_q) for lagged house prices in the IS curve (6.6)' is assumed to be gamma distributed with a mean of 0.02 and a standard error of 0.005, which is a very tight distribution as in Kim and Woo (2008). The prior distribution of the parameter (γ_q) for expected variable in the house-price equation (6.23) is assumed to follow a beta distribution with a mean of 0.5 and a standard error of 0.2, as in that of the parameters $\{\alpha_\pi, \beta_y\}$. The slope parameter of the house-price equation, γ_i , is assumed to be gamma distributed with a mean of 0.05 and a standard error of 0.01. Finally, the prior mean of the third policy parameter, ϕ_q , is pre-set at 0.1, which is somewhat small compared to that of the parameter for the output gap as in Iacoviello (2005).

6.5.3 Posterior Estimates of the Parameters

In addition to the prior distributions, Tables 6.3~6.5 present the results of parameter estimation. The fourth to sixth columns report the mean and the 5th and 95th percentile of the posterior distribution of the parameters. Overall, the estimated posterior

parameters appear to be reasonable and statistically significant. The estimated posterior means of the main behavioural parameters are typically close to the means of the prior assumptions. The mean of α_π , meaning the degree of forward-looking behaviour in the Phillips curve, is estimated to be around 0.36, indicating a somewhat significant role in the baseline model, and the mean of α_π of the alternative model is estimated to be a rather high value of 0.49. The posterior means of β_y are estimated to be from 0.69 to 0.73, which is higher than assumed in the prior distribution. These estimated results support the traditional forward-looking Phillips curve and the Euler equation.

Turning to estimates of policy reaction parameters, the means of the long-run reaction coefficient to inflation, ϕ_π , are estimated to be 1.61 for the baseline model and 1.65 for the alternative model, which are a bit higher than assumed a priori. These results imply that policy appears to respond very strongly to inflation. The Taylor principle is fulfilled in all the models. In contrast, the mean of long-run reaction coefficient to the output gap, ϕ_y , is estimated to be around 0.47, indicating that policy reacts less strongly to the output-gap change than to inflation. The mean of the coefficient on the lagged interest rate, ρ , is estimated to be around 0.89, indicating that there is a considerably high degree of interest-rate smoothing. Finally, the stochastic processes for the exogenous disturbances for the Phillips curve, the IS equation and the house-price equation are estimated to be relatively persistent with an AR(1) coefficient of 0.52, 0.48 and 0.58, respectively for the case without considering house-price movements, and 0.51, 0.47 and 0.60, respectively for the case considering house-price movements in the alternative model, while those for the monetary policy rule equation

are estimated to be less persistent with an AR(1) coefficient of 0.39 and 0.40, respectively.

Note that the posterior distributions (in the darker lines) of each parameter are contrasted against the given prior distributions (see Figures C.6.1~6.3 in Appendix C).

Table 6.3: Distributions of the Parameters: Prior Densities and Posterior Estimates
(Under the Baseline Model)

Parameter	Prior				Posterior		
	Domain	Dist.	Mean	St. Error	Mean	Confidence interval	
						5%	95%
δ	\mathbf{R}^+	gamma	0.987	0.05	0.9077	0.8310	0.9911
α_π	[0,1)	beta	0.5	0.2	0.3614	0.2017	0.5153
α_y	\mathbf{R}^+	gamma	0.15	0.01	0.1389	0.1250	0.1547
β_y	[0,1)	beta	0.5	0.2	0.6855	0.6050	0.7687
β_i	\mathbf{R}^+	gamma	0.05	0.01	0.0581	0.0400	0.0750
ϕ_π	\mathbf{R}^+	gamma	1.5	0.2	1.6083	1.3404	1.9313
ϕ_y	\mathbf{R}^+	gamma	0.5	0.1	0.4788	0.3245	0.6357
ρ	\mathbf{R}^+	gamma	0.8	0.2	0.8942	0.8538	0.9377
ρ_u	\mathbf{R}	normal	0.6	0.1	0.4381	0.3120	0.5690
ρ_v	\mathbf{R}	normal	0.6	0.1	0.4907	0.3925	0.5903
ρ_e	\mathbf{R}	normal	0.6	0.1	0.4214	0.3035	0.5490
σ_u	\mathbf{R}^+	inv. gamma	0.5	0.02	0.5526	0.4664	0.6285
σ_v	\mathbf{R}^+	inv. gamma	0.5	0.02	0.4738	0.4227	0.5261
σ_e	\mathbf{R}^+	inv. gamma	0.5	0.02	0.4525	0.4093	0.4938

Note: The posterior distributions are obtained using the Metropolis-Hastings algorithm.

Table 6.4: Distributions of the Parameters: Prior Densities and Posterior Estimates
(Under the Alternative Model)

(No consideration of house-price fluctuations in the policy reaction rules)

Parameter	Prior				Posterior		
	Domain	Dist.	Mean	St. Error	Mean	Confidence interval	
						5%	95%
δ	\mathbf{R}^+	gamma	0.987	0.05	0.8793	0.8210	0.9409
α_π	[0,1)	beta	0.5	0.2	0.4918	0.4600	0.5224
α_y	\mathbf{R}^+	gamma	0.15	0.01	0.1375	0.1209	0.1519
β_y	[0,1)	beta	0.5	0.2	0.7345	0.6581	0.8122
β_i	\mathbf{R}^+	gamma	0.05	0.01	0.0578	0.0413	0.0758
β_q	\mathbf{R}^+	gamma	0.02	0.005	0.0230	0.0152	0.0298
γ_q	[0,1)	beta	0.5	0.2	0.5756	0.5319	0.6209
γ_i	\mathbf{R}^+	gamma	0.05	0.01	0.0532	0.0366	0.0693
ϕ_π	\mathbf{R}^+	gamma	1.5	0.2	1.6475	1.3409	1.9254
ϕ_y	\mathbf{R}^+	gamma	0.5	0.1	0.4807	0.3410	0.6238
ρ	\mathbf{R}^+	gamma	0.8	0.2	0.8853	0.8487	0.9228
ρ_u	\mathbf{R}	normal	0.6	0.1	0.5205	0.4101	0.6212
ρ_v	\mathbf{R}^+	gamma	0.6	0.1	0.4781	0.3831	0.5853
ρ_w	\mathbf{R}	normal	0.6	0.1	0.5847	0.5146	0.6630
ρ_e	\mathbf{R}	normal	0.6	0.1	0.3924	0.2718	0.5109
σ_u	\mathbf{R}^+	inv. gamma	0.5	0.02	0.4954	0.4483	0.5472
σ_v	\mathbf{R}^+	inv. gamma	0.5	0.02	0.4901	0.4304	0.5436
σ_w	\mathbf{R}^+	inv. gamma	0.5	0.02	0.5092	0.4426	0.5781
σ_e	\mathbf{R}^+	inv. gamma	0.5	0.02	0.4456	0.4061	0.4835

Note: The posterior distributions are obtained using the Metropolis-Hastings algorithm.

Table 6.5: Distributions of the Parameters: Prior Densities and Posterior Estimates
(Under the Alternative Model)

(Consideration of house-price fluctuations in the policy reaction rules)

Parameter	Prior				Posterior		
	Domain	Dist.	Mean	St. Error	Mean	Confidence interval	
						5%	95%
δ	\mathbf{R}^+	gamma	0.987	0.05	0.8767	0.8213	0.9390
α_π	[0,1)	beta	0.5	0.2	0.4941	0.4586	0.5257
α_y	\mathbf{R}^+	gamma	0.15	0.01	0.1369	0.1226	0.1515
β_y	[0,1)	beta	0.5	0.2	0.7236	0.6456	0.7973
β_i	\mathbf{R}^+	gamma	0.05	0.01	0.0568	0.0389	0.0738
β_q	\mathbf{R}^+	gamma	0.02	0.005	0.0237	0.0168	0.0313
γ_q	\mathbf{R}^+	gamma	0.5	0.2	0.5806	0.5331	0.6250
γ_i	\mathbf{R}^+	gamma	0.05	0.01	0.0514	0.0360	0.0657
ϕ_π	\mathbf{R}^+	gamma	1.5	0.2	1.6385	1.3284	1.9313
ϕ_y	\mathbf{R}^+	gamma	0.5	0.1	0.4680	0.3163	0.6226
ϕ_q	\mathbf{R}^+	gamma	0.1	0.005	0.1005	0.0924	0.1088
ρ	\mathbf{R}^+	gamma	0.8	0.2	0.8869	0.8486	0.9236
ρ_u	\mathbf{R}	normal	0.6	0.1	0.5085	0.4071	0.6120
ρ_v	\mathbf{R}	normal	0.6	0.1	0.4698	0.3629	0.5281
ρ_w	\mathbf{R}	normal	0.6	0.1	0.6017	0.5281	0.6737
ρ_e	\mathbf{R}^+	inv. gamma	0.6	0.1	0.4045	0.2881	0.5296
σ_u	\mathbf{R}^+	inv. gamma	0.5	0.02	0.5009	0.4493	0.5528
σ_v	\mathbf{R}^+	inv. gamma	0.5	0.02	0.4852	0.4271	0.5393
σ_w	\mathbf{R}^+	inv. gamma	0.5	0.02	0.5051	0.4463	0.5660
σ_e	\mathbf{R}^+	inv. gamma	0.5	0.02	0.4467	0.4038	0.4876

Note: The posterior distributions are obtained using the Metropolis-Hastings algorithm.

6.5.4 Quantitative Results

6.5.4.1 The Response Coefficients and Loss Values

Table 6.6 provides a variety of results for the optimal and estimated policy rules where estimated rules are obtained by estimating the structural model with the Bayesian approach. All the results for the *optimal* policy rules are obtained by simulating each model. The coefficients of the optimal rules that minimise loss values are calculated by a grid-search method: in each rule, the reaction coefficients of the inflation gap change by 0.01 in the range of 1.3~2.3, and the reaction coefficients of the output gap vary by 0.01 in the range of 0.3~0.6, and those of the house-price gap also change by 0.005 in the range of 0.08~0.12. All the loss values are calculated for every combination of policy reaction coefficients. The weight on the inflation gap in the loss function is normalised as unity. And relative weights on the output gap (λ) and the interest rate (ν) are computed by a grid-search method as well: we increase them by 0.1 within the range of 0.3~0.6. The chosen weights on the output gap and interest rate are 0.5 and 0.2, respectively.

As shown in Table 6.6, the loss values in the optimal policy rules are all smaller than those in the estimated rules. Under the baseline model without a house-price variable in the IS curve and the policy rule, the combination (ϕ_π and ϕ_y) of optimal reaction coefficients for the inflation gap and the output gap that minimise the loss function are 1.99 and 0.41 where the loss value is 15.418, which is smaller than that of the estimated rule, 19.220 (see the first and second rows in Panel A). Under the alternative model with a house-price variable in the IS curve and the policy rule, the

combination (ϕ_π , ϕ_y and ϕ_q) of optimal coefficients for the inflation gap, the output gap and house-price gap that minimise the loss function are 2.07, 0.36 and 0.12 where the loss value is 10.834, which is smaller than that of the estimated rule, 12.879 (see the third and fourth rows in Panel B). In the meantime, under the alternative model, to see how the loss value changes in the case where the central bank does not care about the house-price fluctuations, we discard the house-price variable from the policy rule. As a result, the combination (ϕ_π and ϕ_y) of optimal coefficients of the inflation and the output gap that minimises the loss function are 1.77 and 0.47 where the loss value is 11.939, which is smaller than that of the estimated rule, 12.594 (see the first and second rows in Panel B); and this loss value is bigger than that for the case of considering house prices when implementing monetary policy. Particularly, in the optimal rule caring about house-price movements under the alternative models, the volatility of the interest rate is slightly greater than that of the optimal rule when not caring about house prices. But volatilities for the inflation gap and the output gap are relatively smaller than those of the optimal rules which do not care about house prices. These results imply that when the central bank actively responds to fluctuations in house prices, it can decrease the social losses, leading to economic stability. However, it is notable that there might be an increasing volatility in interest rates. This is because the central bank, by adjusting its policy instruments (*i.e.*, the short-term nominal interest rate), directly reacts to movements in house prices when they are highly volatile.

Table 6.6: Response Coefficients and Loss Values

		Reaction Coefficients			Volatility Results of Goal Variables			Min. Loss
		ϕ_{π}	ϕ_y	ϕ_q	$\text{Var}(\pi_t)$	$\text{Var}(y_t)$	$\text{Var}(i_t)$	
Panel A.								
Under Baseline Model	Optimal Rule (Policy Rule 1)	1.99	0.41	–	11.086	6.139	6.313	15.418
	Estimated Rule (Policy Rule 1)	1.61	0.48	–	14.701	6.633	6.013	19.220
Panel B.								
Under Alternative Model	Optimal Rule (Policy Rule 1)	1.77	0.47	–	9.155	4.361	3.017	11.939
	Estimated Rule (Policy Rule 1)	1.65	0.48	–	9.807	4.424	2.873	12.594
	Optimal Rule (Policy Rule 2)	2.07	0.36	0.12	7.975	4.403	3.289	10.834
	Estimated Rule (Policy Rule 2)	1.64	0.47	0.10	10.048	4.524	2.845	12.879

6.5.4.2 The Impulse Response Analysis

We examine the impulse responses of the variables to the structural shocks. As explained in Subsection 6.4.2, there are three shocks in the baseline model: the supply shock (u_t), the demand shock (v_t), and the interest rate shock (e_t). Each shock is given one standard deviation of corresponding disturbance terms. Figure D.6.1 in Appendix D plots the impulse responses of inflation, the output gap and interest rate over 24 quarters to those shocks, respectively, using the estimated parameters. The exogenous supply shock, which causes the inflation rate to deviate from its long-run level, is transmitted to three variables through the dynamic structure of the model. The positive supply shock (*i.e.*, the cost-push shock) directly increases inflation, and immediately leads to a drop in the output gap, while it causes the interest rate to rise. The positive demand shock causes an increase in the output gap, increases inflation at the same time, and leads to a rise in

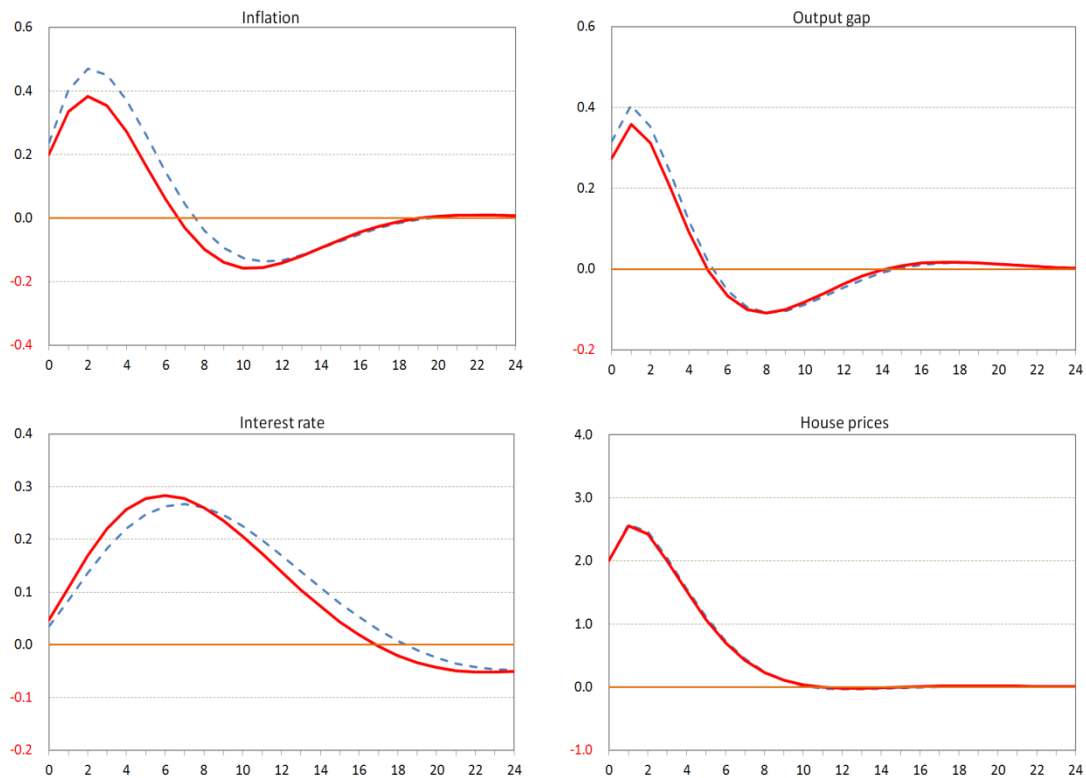
interest rate. Finally, when the interest rate shock or the monetary policy shock occurs, inflation and the output gap decrease immediately. Note that the responses to these unexpected shocks die out to zero after all, as the estimated model system is stationary. On the whole, the impulse response functions for each structural shock seem to be quite reasonable in an economic sense.

Turning to the alternative model, there are four structural shocks including the exogenous shock to the house prices (w_t). Figures D.6.2 and D.6.3 in Appendix D show the impulse responses of inflation, the output gap, house prices and interest rate over 24 quarters to those individual shocks. The difference between the two figures is that the former is the case in which the central bank does not care about the house-price fluctuations when implementing its monetary policy, while the latter is the case in which the central bank does. These impulse responses based on the alternative model are quite similar to their corresponding ones in the baseline model. The positive monetary policy shock (*i.e.*, an increase in interest rate) leads to a decrease in house prices, as the positive supply and demand shocks do. The relationship between the monetary policy shock and house prices coincides with economic theory. Responses of house prices to the demand shock and the monetary policy shock occur immediately after the shocks, but the response of house prices to the supply shock appears after one quarter. This result reflects the dynamic structure of the model.

In order to compare the magnitude of impulse responses of variables to the exogenous shock to the house prices, we draw each impulse response in the same panels for the alternative model. As plotted in Figure 6.5, each graph contains two sets of impulse responses of individual variables: one corresponds to the case where the central bank

ignores house-price fluctuations (the blue dashed lines) and the other corresponds to the case where it reacts to fluctuations in house prices (the red solid lines). The magnitudes of responses of the inflation and the output gap in the model that take into consideration house-price fluctuations are smaller than that in the model that does not. In contrast, the response of the interest rate in the model that takes into account house-price fluctuations is greater than that in the model not taking them into account. This is because the model is designed in a way in which the central bank reacts to changes in house prices. The findings that come from quantitative simulations are confirmed by the impulse response analysis.

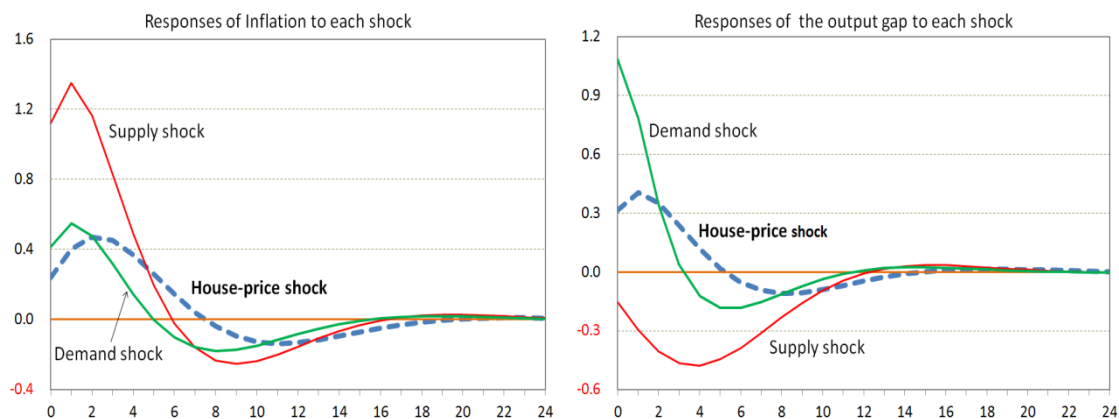
Figure 6.5: Responses to the House-price Shock under the Alternative Model



Note: The blue dashed lines represent the responses from the alternative model that ignores house-price fluctuations in the monetary policy. The red solid lines represent the responses from the alternative model where the central bank reacts to fluctuations in house prices.

As compared with in Figure 6.6 below, it is interesting to note that the initial response of inflation to the house-price shock is smaller than those to the supply and the demand shocks, and that the initial response of the output gap to the house-price shock is smaller than that to the demand shock. But, overall, the persistence of the responses to the house-price shock is longer than that caused by the supply and the demand shocks.

Figure 6.6: Comparison of the Degree of Responses and Persistence



6.6 Conclusion

Whether central banks should react to asset prices or not is a highly controversial issue, both from an academic perspective and from policymakers' point of view.

Before the GFC of 2007–2009, provoked by the US sub-prime mortgage market, it was widely accepted that central banks did not need to directly react to asset-price fluctuations as long as inflation could be under control, and accordingly they did not need to care seriously about asset prices unless the asset prices played an informational

role to help forecast future inflation. In addition, it was argued that if central banks reacted to asset prices or even further targeted them, the asset markets could be distorted, potentially leading to economic inefficiency. Another reason why most central banks tend to be cautious in responding to pronounced rises in house prices was that it might be difficult to identify whether they were derived from the changes in fundamental economic conditions or the formation of the bubble. As a result, many central banks formed a so-called ‘benign neglect’ view towards a house-price boom in the early and middle 2000s.

In the aftermath of the GFC, however, there has been growing consensus that the ‘benign neglect’ view should be reconsidered. In other words, central banks should preemptively try to burst, or at least slow, the growth of asset-price bubbles by raising interest rates, even though current or near-term inflation remains subdued, so as to minimise damage to the economy after a bubble burst.

This chapter examined whether the central bank should react directly to movements in asset prices such as house prices. We built a forward-looking model that is composed of the Phillips curve, the IS curve and monetary policy reaction rules, forming a small dynamic stochastic general equilibrium (DSGE) model. This small DSGE framework was set up by the hybrid NK model, working as a baseline model where the central bank is assumed to aim at attaining price stability as a flexible inflation targeter. In addition, we formulated an alternative model where the central bank pursues financial stability as well as price stability. In order to do so, we built a hybrid NK model with a house-price equation which is included to represent financial instability caused by large swings in

house prices. Essentially, the purpose of this chapter is to explore which policy choice is more effective with respect to policy validity between the one focusing mainly on price stability only and the other emphasising asset-price volatility in addition to price stability.

In this chapter, we demonstrated what could be the best response of central banks to changes in house prices for the purpose of achieving economic stability. We attempted to compare the effectiveness of a policy pursuing price stability to that of policy considering changes in house prices in terms of the central bank's loss values.

The main empirical results in this respect are the following: firstly, we found evidence indicating that house prices may convey some useful information on conditions such as possible financial instability and inflation in Korea; secondly, the house-price shock differs from other shocks to the macroeconomy in that it has persistent impacts, causing economic volatility in Korea; thirdly, the central bank could reduce its loss values in terms of economic volatility, thereby leading to growing economic stability when it responds more directly to fluctuations in house prices. In the absence of policy reaction, the resulting loss of the central bank could be larger. This finding is also confirmed by the impulse response analysis. The third finding, especially, provides a rationale for why central banks should pay much attention to movements in asset prices, especially house prices in the conduct of monetary policy. In other words, the central bank policymakers should respond to possible house-price misalignments associated with credit bubbles because their busting could result in episodes of financial instability as witnessed in the process of global financial crises.

Chapter 7

Summary and Conclusions

7.1 Introduction

Central banks always face uncertainties, and thus must take them into account when conducting their monetary policy. In Greenspan's famous phrase, uncertainty is not just an important feature of the monetary policy landscape, but also a salient characteristic of that landscape. Uncertainty influencing the implementation of monetary policy comes from various sources including imperfect knowledge about the ever-changing economy, and from unexpected internal or external shocks. This uncertainty faced by the monetary policymakers is normally classified into three types: data uncertainty; parameter uncertainty; and model uncertainty.

In this context, this thesis attempted to find answers on the following issues: *i*) what are the different types of uncertainty confronting central banks, and how can these be formally introduced into econometric models for monetary policy analysis? *ii*) is the behaviour of monetary policymakers in practice consistent with the predictions made by

the theoretical models of monetary policy under uncertainty? *iii*) how has such uncertainty affected the actual operation of monetary policy in Korea? and *iv*) should central banks directly respond earlier to the sharp increase in asset prices?

In order to answer the above questions, this thesis dealt with: *i*) setting up theoretical and empirical models of monetary policy under uncertainty; *ii*) exploring the effect of uncertainty on the operation of monetary policy since the adoption of interest rate-oriented policy in Korea; *iii*) investigating whether gradual adjustment in policy rates can be explained by uncertainty; and *iv*) examining whether central banks should take into account house-price fluctuations in formulating monetary policy in Korea.

7.2 Summary: main findings and implications

The main findings and implications from theoretical and empirical research from Chapters 3 to 6 are summarised in the following: first of all, Chapter 3 discussed some stylised facts in policy rate adjustment practices and attempted to show the empirical evidence that there exists gradual adjustment behaviour in policy interest rates in Korea. We found that there are four stylised facts regarding the policy interest rate path in Korea: infrequent changes in policy rates; successive changes in the same direction; asymmetric adjustments in terms of the size of interest-rate changes for continuation and reversal periods; and a long pause before reversals in policy rates. These patterns of policy rates, which are dubbed ‘interest-rate smoothing’, characterise the central bank’s reaction to inflation and the output gap as being less aggressive than the optimising central bank behavior would predict. Central banks’ smoothing of policy rates may be optimal behaviour for a variety of reasons, not least of which is that they conduct monetary

policy in a considerably uncertain world. When operating the policy strategies, they are always confronted with uncertainty about the evolution of economic activity and the impact of their policy actions on the ultimate policy goals, such as inflation and real output stabilisation.

Chapter 4 examined whether the parameter uncertainty, meaning uncertainty about the monetary policy transmission mechanism to economic activities, matters in the conduct of monetary policy in Korea. We found that uncertainty can provide a rationale for a smoother path of the policy interest rate in Korea. In particular, since the introduction of an interest rate-oriented monetary policy in 1998, the call money rates have shown to be similar to the optimal rate path under parameter uncertainty. It is found that gradual movements in the policy rates do not necessarily imply that the central bank has an interest-rate smoothing incentive. Parameter uncertainty can account for a vast portion of the observed gradual movements in policy interest rates.

The main implications of this chapter are: firstly, if we consider exclusively additive uncertainty when analysing monetary policy, it is nearly impossible to explain the actual behaviour of monetary policy conducted by the central bank. It is found that there exists substantial difference between the observed policy interest rate and the optimal policy rate; secondly, the optimal policy rate path under parameter uncertainty is much closer to the actual policy rate path than those under only additive uncertainty. This empirical evidence implies that monetary policy in Korea has been conducted in consideration of the possibility of parameter uncertainty. The central bank policymakers have given much attention to the possibility of occurrence of parameter uncertainty, therefore conducting

the monetary policy in a cautious and gradual manner; Lastly, even though there is no interest-rate smoothing motive in the central bank's objective function, the central bank showed a tendency to behave as if they carry out interest-rate smoothing, if we assume that there exists parameter uncertainty in the economy.

Chapter 5 investigated how the presence of data uncertainty can influence the policy-making, and explored how the optimal policy rules change when uncertainty on data such as the output gap and inflation increases. We found that the greater output-gap uncertainty, the smaller the output response coefficients in the optimal rules; and similarly, the greater the inflation uncertainty, the smaller the inflation response coefficients.

The optimal policy rules derived by using data without errors showed the large size of the output-gap and inflation response coefficients. In general, the evaluation of monetary policy in most empirical studies relies on the unrealistic assumption that policymakers know for sure the current state of the economy without any errors. But, it may be true that central banks face a large amount of uncertainty about the actual state of the economy when setting their policy rates. This implies that data uncertainty can be one of the sources explaining the reasons why monetary policymakers act less aggressively in setting their interest rate instrument. Traditionally, however, central bank preferences imply a bigger weight on inflation relative to the output gap: this might reduce the impact of output-gap uncertainty on the conduct of monetary policy, therefore making the issue of data uncertainty on the output gap less crucial than that on inflation.

In this section, it may be worth discussing which type of multiplicative uncertainty (parameter vs. data) is more plausible to justify an interest-rate smoothing behaviour from the central bank. It might be said that parameter uncertainty is more seriously accepted than data uncertainty in that the latter is to a large extent inevitable to central bankers in the actual conduct of monetary policy.

Lastly, Chapter 6 examined how the central bank should implement monetary policy in the presence of high volatility in asset prices such as house prices, and asset-price bubbles. To this end, we built a forward-looking structural model that consists of the Phillips curve, the IS curve and monetary policy reaction rules, forming a small dynamic stochastic general equilibrium (DSGE) model. This small DSGE framework was based on the hybrid version of the New Keynesian (NK) model, where asset prices affect the DISC.

The main empirical findings are: firstly, house prices conveyed some useful information on conditions such as financial instability and future inflation in Korea; secondly, the house-price shock had persistent impacts on the real economy, consequently provoking much larger economic volatility in Korea, different from the supply or demand shock to the economy; and thirdly, the central bank could reduce its loss values in terms of economic volatility, thereby leading to growing economic stability when it responds more directly to fluctuations in house prices. This finding provides the reason why the central bank should pay more attention to house-price movements.

Concerning the role of central banks, in the aftermath of the GFC, it is widely accepted that they should pre-emptively try to burst, or at least slow, the growth of asset-

price bubbles by raising interest rates, even though current or near-term inflation remains subdued, in order to reduce damage to the real economy after a bubble burst.

7.3 Limitations and Future Research Scope

Research methodology and results in this thesis have several limitations. Above all, the research has been carried out throughout the chapters under the assumption of a closed economy for analytic simplicity and convenience. But, if we assume an open economy, the empirical results may be changed in terms of the magnitude and persistence of impact of uncertainty on the economy, and the degree of the effect of monetary policy on asset prices. Of course, it is expected that such an assumption might not overturn the thesis's empirical findings. Nonetheless, it would be interesting to extend the models to a framework of an open economy analysis, by including, for example, an exchange rate variable within the models.

Next, as regards the relationship between parameter uncertainty and monetary policy, we did not touch the case that suggests the activist prescription for monetary policy, which could weaken the degree of completion of this study. Hence, this thesis can be extended to the case that deals with parameter uncertainty, especially uncertainty about the degree of inflation persistence. This issue is very important as a more aggressive response to shocks may be more appropriate when central banks face this sort of uncertainty. This policy prescription overturns the Brainard conservatism principle, which is regarded as general wisdom in the operation of monetary policy. In addition, we can possibly extend the model employed in Chapter 4 to allow for an extra variable in the loss function, the

change in interest rate. This extra element would allow us to assess the importance of interest-rate smoothing.

Turning to model uncertainty, which is one of the important sources of uncertainty discussed in the literature review section, we did not deal with it in terms of in-depth analysis in this thesis. As a matter of fact, model uncertainty about the dynamic structure of the economy may be a much more crucial issue than other types of uncertainty for the analysis of monetary policy. We have no common consensus on the appropriate models. Therefore, monetary policy analysis in the presence of model uncertainty can be an interesting topic for the future research.

Finally, in order to examine how the central bank should respond to movements in house prices, we used a small DSGE model composed of the Phillips curve, the IS curve and monetary policy reaction rules, based on a forward-looking approach. Even though this model is simple and convenient to handle, such a simplified DSGE model is not enough to do in-depth analysis about complicated relationships between asset prices and monetary policy. The model used in Chapter 6 could be extended to construct models with explicit and more elaborate financial sectors within full-fledged DSGE models. These extensions could be realised by focusing on containing particular financial variables or frictions.

In the meantime, we focused on monetary policy using interest rates as policy instruments for the achievement of economic stability through financial stability. But, as frequently pointed out in recent literature, for example Allen and Rogoff (2011), monetary policy alone is unlikely to be successful in effectively attaining financial

stability. To buttress the effects of monetary policy, other policies, particularly macroprudential ones, are likely to be needed. As an extension of this thesis, a more in-depth analysis, for instance, on the effects of changes in liquidity ratios and loan-to-value ratios for monetary and house-price dynamics and their interactions, would be an interesting topic for future research on the Korean economy.

Appendices

Appendix A. The Derivation of the *Basic* New Keynesian (NK) Model

For simplification, we consider the closed economy with no capital accumulation. Additionally, as is done in the recent numerous literature, we assume a cashless economy.

The model is composed of households and firms: households supply labour and purchase goods for consumption; firms produce differentiated goods by hiring labour, and sell them in monopolistically competitive markets. And they both behave optimally: households and firms maximise their utility and profits, respectively. The model is “*basic*” due to the fact that it features only one nominal rigidity and one real rigidity. The nominal rigidity is given by staggered price adjustment as in Calvo (1983) and the real rigidity comes from monopolistic competition in the goods markets, which is modelled as in Dixit and Stiglitz (1977).

The NK model in this appendix is derived according to Galí (2008) and Walsh (2010), among others.

A.1. Households

There is a continuum of households of size one. The representative household seeks to maximise the expected present discounted value of utility of the form:

$$(A.1) \max E_t \sum_{i=0}^{\infty} \delta^i \left\{ \frac{1}{1-\gamma} C_{t+i}^{1-\gamma} - \frac{1}{1+\gamma_n} N_{t+i}^{1+\gamma_n} \right\}$$

$$(A.2) \text{ subject to } C_t = \frac{W_t}{P_t} N_t + \frac{B_t}{P_t} - \left(\frac{1}{1+i_t} \right) \frac{B_{t+1}}{P_t}$$

where B_t : a nominal discount bond that pays \$1 at time $t+1$.

C_t : an aggregate of the household's consumption of a continuum of individual goods.

P_t : the aggregate price index (price of the final goods).

N_t : hours of work or labour supply.

W_t/P_t : the real wage.

γ : the inverse of the intertemporal elasticity of substitution or the coefficient of relative risk aversion of households.

γ_n : the inverse of the labour supply elasticity with respect to the real wage.

i_t : the short-term nominal interest rate.

Following Dixit and Stiglitz (1977), the consumption aggregate is defined as:

$C_t = \left(\int_0^1 C_t(z)^{\varepsilon-1/\varepsilon} dz \right)^{\varepsilon/\varepsilon-1}$, where $\varepsilon > 1$ is the constant elasticity of substitution between goods. Maximising utility function (A.1) subject to the intertemporal budget constraint yields the optimal allocation of consumption across time:

$$(A.3) \quad C_t^{-\gamma} = \delta(1+i_t)E_t\left(\frac{P_t}{P_{t+1}}C_{t+1}^{-\gamma}\right),$$

And the optimal supply of labour is:

$$(A.4) \quad \frac{W_t}{P_t}C_t^{-\gamma} = N_t^{\gamma_n} \quad \text{or} \quad \frac{W_t}{P_t} = C_t^{\gamma}N_t^{\gamma_n}$$

Equations (A.3) and (A.4) are the well-known results of first-order conditions for consumption and labour, respectively. Particularly, (A.3) is the familiar intertemporal Euler equation for consumption.

A.2. Firms

(Market Demand for Intermediate Goods)

Assume a continuum f of final goods producers whose individual demand for good z depends on relative prices and individual production:

$$(A.5) \quad Y_t^f(z) = \left(\frac{P_t(z)}{P_t} \right)^{-\varepsilon} Y_t^f, \text{ where } P_t(z) \text{ denotes the price of good } z.$$

Then, market demand for good z is:

$$(A.6) \quad Y_t(z) = \int_0^1 Y_t^f(z) df \\ = \left(\frac{P_t(z)}{P_t} \right)^{-\varepsilon} Y_t, \text{ where } Y_t = \int_0^1 Y_t^f df \text{ denotes total final good demand.}$$

Assume that intermediate goods producers have CRS homogeneous production functions:

$$(A.7) \quad Y_t(z) = A_t N_t(z), \text{ where } A_t \text{ denotes technology.}$$

With flexible prices, a firm choose $P_t(z)$ to maximize its profits, $\Phi_t(z)$:

$$(A.8) \quad \Phi_t(z) = \frac{P_t(z)}{P_t} Y_t(z) - \frac{W_t}{P_t} N_t(z),$$

$$(A.9) \quad \text{subject to } Y_t(z) = \left(\frac{P_t(z)}{P_t} \right)^{-\varepsilon} Y_t.$$

(Marginal Cost)

Define real marginal cost MC_t as:

$$(A.10) \quad MC_t = \frac{W_t / P_t}{A_t}, \text{ then costs are } W_t N_t(z) = MC_t P_t Y_t(z).$$

The firms solve the problem to maximise their profits:

$$(A.11) \quad \max_{P_t(z)} \left[\left(\frac{P_t(z)}{P_t} \right)^{1-\varepsilon} - MC_t \left(\frac{P_t(z)}{P_t} \right)^{-\varepsilon} \right] Y_t.$$

The FOC implies that the firm sets its relative price $P_t(z)/P_t$ as:

$$(A.12) \quad \frac{P_t(z)}{P_t} = (1 + \mu) MC_t,$$

where $(1 + \mu) = \varepsilon / (\varepsilon - 1)$ denotes a constant markup over real marginal cost.

(Firm's Problem)

Following the formalism proposed in Calvo (1983), each firm resets its price with probability, $(1 - \theta)$. A fraction that keeps price unchanged is θ . Hence, the expected average duration a price remains fixed is given by $(1 - \theta)^{-1}$. Hence, the parameter, θ gives a natural index of price stickiness.

(Aggregate Price Dynamics)

The aggregate price index satisfies:

$$(A.13) \quad P_t = \left(\int_0^1 P_t(z)^{1-\varepsilon} dz \right)^{1/(1-\varepsilon)}.$$

Under Calvo price setting, a fraction $1 - \theta$ of firms reset their price to P_t^* while a fraction θ leaves their price constant. We hence have:

$$(A.14) \quad P_t = \left[\theta \int_0^1 P_{t-1}(z)^{1-\varepsilon} + (1 - \theta)(P_t^*)^{1-\varepsilon} \right]^{\frac{1}{1-\varepsilon}}.$$

The aggregate price level at time t depends on geometric weighted average of price, P_{t-1} at time $t - 1$ and the optimal reset price, P_t^* at t :

$$(A.15) \quad P_t = \left[\theta (P_{t-1})^{1-\varepsilon} + (1 - \theta)(P_t^*)^{1-\varepsilon} \right]^{\frac{1}{1-\varepsilon}}.$$

Equivalently, dividing both sides by P_{t-1} :

$$(A.16) \quad \Pi_t = \left[\theta + (1-\theta) \left(\frac{P_t^*}{P_{t-1}} \right)^{1-\varepsilon} \right]^{\frac{1}{1-\varepsilon}}, \text{ where } \Pi_t \equiv P_t/P_{t-1}. \text{ Notice that in a steady-state with zero inflation } P_t^* = P_{t-1} = P_t, \text{ for all } t.$$

Here, it is useful to note that lower-case letters denote the natural logs of the corresponding variable (*i.e.*, $x_t = \log(X_t)$).

Log-linearisation of (A.16) around $P_t^*/P_{t-1} = 1$ implies:

$$(A.17) \quad (1-\varepsilon)\ln\Pi_t = \ln\left[\theta + (1-\theta)\left(\exp((1-\varepsilon)(P_t^* - P_{t-1}))\right)\right].$$

Since $\pi_t = \log(\Pi_t) = p_t - p_{t-1}$, $p_t^* = \log(P_t^*)$ and $p_{t-1} = \log(P_{t-1})$, (A.17) can be re-written in log-linear form as follows:

$$(A.18) \quad (1-\varepsilon)\pi_t = \left[\theta + (1-\theta)\exp((1-\varepsilon)(p_t^* - p_{t-1}))\right].$$

We can approximate RHS of (A.18) as:

$$\begin{aligned} & \theta + (1-\theta)\exp((1-\varepsilon)(p_t^* - p_{t-1})) + \\ & \frac{(1-\theta)\exp((1-\varepsilon)(p^* - p))}{\theta + (1-\theta)\exp((1-\varepsilon)(p^* - p))} [(1-\varepsilon)(p_t^* - p_{t-1}) - (p^* - p)]. \end{aligned}$$

If inflation is zero in a steady-state, then $p^* = p$ and RHS reduces to $(1-\theta)(1-\varepsilon)(p_t^* - p_{t-1})$.

Plugging this result into (A.18) and rearranging yields:

$$(A.19) \quad \pi_t = (1-\theta)(p_t^* - p_{t-1}) \text{ or } p_t = \theta p_{t-1} + (1-\theta)p_t^*.$$

Calvo price-setting implies a partial adjustment mechanism whereby inflation responds by a constant fraction of the gap between the optimal reset-price and the existing price-level.

(Optimal Reset Price)

A firm reoptimising at time t will choose P_t^* to maximize the current market value of the profits, so it solves the following problem:

$$(A.20) \quad \max E_t \sum_{i=0}^{\infty} \theta^s \left\{ \bar{\Lambda}_{t,t+s} \left(P_t^* Y_{t+s|t} - \overline{MC}_{t+s} Y_{t+s|t} \right) \right\},$$

subject to the sequence of the demand constraints:

$$(A.21) \quad Y_{t+s|t} = \left(\frac{P_t^*}{P_{t+s}} \right)^{-\varepsilon} Y_{t+s}.$$

For $s = 0, 1, 2, \dots$, where $\bar{\Lambda}_{t,t+s}$ denotes the household's nominal stochastic discount factor between time t and $t + s$, \overline{MC}_{t+s} is nominal marginal cost which is assumed given, and $Y_{t+s|t}$ denotes the output at time $t + s$ for a firm that last reset its price at time t .

The FOC associated with the above-mentioned problem is:

$$(A.22) \quad E_t \sum_{s=0}^{\infty} \theta^s \left\{ \bar{\Lambda}_{t,t+s} Y_{t+s|t} \left(P_t^* - (1 + \mu) \overline{MC}_{t+s} \right) \right\} = 0.$$

A.3. The New Keynesian Phillips Curve

(Price vs. Marginal Cost)

If $\theta = 0$, this implies that price is set as a constant markup over marginal cost, so that we get:

$$(A.23) \quad P_t^* = (1 + \mu) \overline{MC}_t.$$

However, if $\theta > 0$, then the optimal reset price is a weighted average of expected future nominal marginal costs. Hence we have:

$$(A.24) \quad P_t^* = (1 + \mu) E_t \sum_{s=0}^{\infty} \left(w_{t,t+s} \overline{MC}_{t+s} \right),$$

$$\text{where } w_{t,t+s} = \frac{\theta^s \bar{\Lambda}_{t,t+s} P_{t+s}^{-\varepsilon} Y_{t+s}}{E_t \sum_{s=0}^{\infty} \left(\theta^s \bar{\Lambda}_{t,t+s} P_{t+s}^{-\varepsilon} Y_{t+s} \right)}.$$

In a steady-state, $\bar{\Lambda}_{t,t+s} = \delta^s$, $Y_{t+s} = Y$, $P_{t+s} = P$, and $w_{t,t+s} = (1 - \delta\theta)(\delta\theta)^s$. Also, in a steady-state:

$$\frac{P_t^*}{P_t} = (1 + \mu) MC_t = 1, \text{ where } MC_t \text{ denotes real marginal cost.}$$

Log-linearising the equation for P_t^* implies:

$$(A.25) \quad p_t^* = (1 - \delta\theta) E_t \sum_{s=0}^{\infty} \left\{ (\delta\theta)^s (\mu + m_{C_{t+s}} + p_{t+s}) \right\}.$$

where mc_{t+s} denotes the log of real marginal cost. In a steady-state, $mc = -\mu$. Note that $w_{t,t+s}$ terms all cancel in the log-linearisation.

Now, we can rewrite (A.25) as:

$$(A.26) \quad p_t^* = (1 - \delta\theta)(\mu + mc_t + p_t) + \delta\theta E_t p_{t+1}^*.$$

which implies that $p_t^* - p_{t-1} = (1 - \delta\theta)(\mu + mc_t) + \pi_t + \delta\theta E_t (p_{t+1}^* - p_t)$.

Since $\pi_t = (1 - \theta)(p_t^* - p_{t-1})$, we have the forward-looking inflation dynamic equation:

$$(A.27) \quad \pi_t = \delta E_t (\pi_{t+1}) + \lambda \hat{mc}_t,$$

where $\lambda \equiv (1 - \theta)(1 - \delta\theta)\theta^{-1}$ is strictly decreasing in the index of price stickiness θ , and $\hat{mc}_t = \mu + mc_t$ denotes the deviations of real marginal cost from its values in a steady-state.

Solving (A.27) forward, inflation can be expressed as the discounted sum of current and expected future deviations of real marginal costs from steady-state values:

$$(A.28) \quad \pi_t = \lambda E_t \sum_{s=0}^{\infty} \delta^s \hat{mc}_{t+s}.$$

(Marginal Cost and the Output Gap)

Log-linearising the production function (A.7) gives:

$$(A.29) \quad \hat{y}_t = \hat{n}_t + \hat{a}_t.$$

From the household's labour supply condition we have:

$$(A.30) \quad \hat{w}_t - \hat{p}_t - \gamma \hat{c}_t = \gamma_n \hat{n}_t.$$

In equilibrium, $\hat{y}_t = \hat{c}_t$, so that

$$(A.31) \quad \begin{aligned} \hat{mc}_t &= \hat{w}_t - \hat{p}_t - \hat{a}_t \\ &= \gamma \hat{y}_t + \gamma_n \hat{n}_t - \hat{a}_t. \end{aligned}$$

Substituting out for \hat{n}_t using the production function (A.29) gives:

$$(A.32) \quad \hat{mc}_t = (\gamma + \gamma_n) \hat{y}_t - (1 + \gamma_n) \hat{a}_t.$$

(The Natural Rate of Output)

Define the natural rate of output as the level of output that occurs when prices are fully flexible. This occurs when

$$1 = \frac{P_t^*}{P_t} = (1 + \mu)MC_t.$$

Taking logs implies $\log MC_t = -\mu$ or $\hat{m}_{Ct} = 0$.

In log-deviations from a steady-state value, define the natural rate \hat{y}_t^n via the equation:

$$(A.33) \quad (\gamma + \gamma_n)\hat{y}_t^n - (1 + \gamma_n)\hat{a}_t = 0 \text{ or } \hat{y}_t^n = \psi_{ya}^n \hat{a}_t, \text{ where } \psi_{ya}^n = \frac{1 + \gamma_n}{\gamma + \gamma_n}.$$

Let $y_t = \hat{y}_t - \hat{y}_t^n$ denotes the output gap. Then from (A.33) and (A.33), we have:

$$(A.34) \quad \hat{m}_{Ct} = (\gamma + \gamma_n)y_t,$$

so that the output gap is proportional to the real marginal costs. Equation (A.34) implies that if $\gamma + \gamma_n > 1$, the real marginal costs are high relative to a steady-state, when the actual output exceeds the natural level of output. The term $\gamma + \gamma_n$ captures the extent to which marginal costs rise as the output gap increases.

Let $\pi_t = \hat{\pi}_t - \pi^*$ which denotes the deviations of inflation rate from its long-run average rate (here, π^* is assumed to be zero).

Finally, combining the marginal cost expression (A.34) with the inflation equation (A.27) leads to the inflation-expectations augmented Phillips curve expressed in terms of the output gap instead of real marginal cost:

$$(A.35) \quad \pi_t = \delta E_t \pi_{t+1} + \kappa y_t, \text{ where } \kappa = (1 - \theta)(1 - \theta\delta)\theta^{-1}(\gamma + \gamma_n),$$

Let us call the above equation the *basic* New Keynesian Phillips curve (NKPC).

Solving this equation forward gives:

$$(A.36) \quad \pi_t = \kappa E_t \sum_{s=0}^{\infty} \delta^s y_{t+s},$$

so that current inflation is an increasing function of the expected future output gaps.

A.4. The *Basic* Dynamic IS Curve

Market clearing in the goods market requires:

$$(A.37) \quad Y_t(z) = C_t(z),$$

for all $z \in [0,1]$ and all t . Letting the aggregate output be defined as $Y_t \equiv \left(\int_0^1 Y_t(z)^{\varepsilon-1/\varepsilon} dz \right)^{\varepsilon/\varepsilon-1}$ follows that $Y_t = C_t$. Or taking logs yields, equivalently, $\hat{y}_t = \hat{c}_t$.

Combining the market clearing condition, $\hat{y}_t = \hat{c}_t$ with the household's intertemporal Euler equation (A.3), and taking logs gives the *basic* dynamic IS curve ('DISC' for short) as below:

$$(A.38) \quad \hat{y}_t = E_t \hat{y}_{t+1} - \gamma^{-1} (i_t - E_t \pi_{t+1}).$$

The real interest rate satisfies the Fisher equation:

$$(A.39) \quad \hat{r}_t = i_t - E_t \pi_{t+1}.$$

Define the natural rate of interest r_t^n as the real interest rate that would prevail when actual output equals the natural level of output:

$$(A.40) \quad \hat{y}_t^n = E_t \hat{y}_{t+1}^n - \gamma^{-1} r_t^n.$$

This implies a positive relationship between the natural rate of interest and expected growth in technology:

$$(A.41) \quad r_t^n = \gamma \psi_{ya}^n E_t \Delta \hat{a}_{t+1}.$$

The *basic* DISC, (A.38) can be expressed in terms of the output gap and the natural rate as:

$$(A.42) \quad y_t = E_t y_{t+1} - \gamma^{-1} (i_t - E_t \pi_{t+1} - r_t^n).$$

Equation (A.42) relates the output gap positively to its expected one-period ahead value, and negatively to the *real* interest rate gap, where the latter is defined as the gap between the real interest rate $i_t - E_t \pi_{t+1}$ and the natural interest rate r_t^n .

Iterating the above equation forward gives:

$$(A.43) \quad y_t = -\gamma^{-1} E_t \sum_{s=0}^{\infty} (\hat{r}_{t+s} - r_{t+s}^n),$$

in which the current output gap depends negatively on the expected real rate of interest relative to the natural rate of interest.

Appendix B. The Derivation of the ‘Hybrid’ New Keynesian Model

This appendix gives a more detailed derivation of the hybrid version of New Keynesian model. First, the hybrid Phillips curve is derived according to Galí (2002), Galí *et al.* (2001), and Sbordone (2002), among others. The derivation leads to generalisation of the Phillips curve rationalised by Fuhrer and Moore (1995). Second, the hybrid IS curve is derived following Sahuc (2002), among others.

B.1. The Hybrid Phillips Curve

As shown in Equation (A.19), the log-linearised aggregate price level is given by:

$$(A.19) \quad p_t = \theta p_{t-1} + (1-\theta) p_t^*,$$

where p_t^* is an index for the prices newly set at time t .

Let p_t^f denote the price set by a forward-looking firm at t and p_t^b the price set by a backward-looking firm. Then the index for newly set prices is expressed as the convex combination of forward-looking and backward-looking price-setting, which is given by:

$$(B.1) \quad p_t^* = (1-\omega) p_t^f + \omega p_t^b.$$

Equation (B.1) implies that a fraction $1-\omega$ of the firms, that we refer to as forward-looking, behave like the firms in Calvo’s model, while the remaining fraction ω , which we refer to as backward-looking, set the price using a simple rule of thumb that is based on recent history of aggregate price behavior.

Forward-looking firms’ optimal reset price may be expressed as:

$$(B.2) \quad p_t^f = (1-\delta\theta\omega) E_t \sum_{s=0}^{\infty} \{(\delta\theta)^s (\hat{m}_{t+s} + p_{t+s})\}, \text{ where } \hat{m}_{t+s} = \mu + m_{t+s}.$$

However, we assume that backward-looking firms set the price according to a rule-of-thumb behavior. Then the log-linearising the backward-looking reset price yields:

$$(B.3) \quad p_t^b = p_{t-1}^* + \pi_{t-1}.$$

Following Woodford (1996), Galí (2002), Galí *et al.* (2001) and Sbordone (2002), marginal cost of forward-looking firms that reset the price at time t , $\hat{m}_{c_{t,t+s}}$ is given by:

$$(B.4) \quad \hat{m}_{c_{t,t+s}} = \hat{m}_{c_{t+s}} - \frac{\varepsilon\alpha}{1-\alpha}(p_t^f - p_{t+s}),$$

where $\hat{m}_{c_{t,t+s}}$ and $\hat{m}_{c_{t+s}}$ are the log deviations of $MC_{t,t+s} = \frac{1}{1-\alpha} \frac{W_{t+s}/P_{t+s}}{Y_{t,t+s}/N_{t,t+s}}$ and $MC_{t+s} = \frac{1}{1-\alpha} \frac{W_t/P_t}{Y_t/N_t}$ from their steady-state average real marginal costs, respectively.

Combining (A.19) and (B.1) delivers the evolutions of the aggregate inflation rate, which is written as:

$$(B.5) \quad \pi_t = \left(\frac{1-\theta}{\theta} \right) \left[(1-\omega)(p_t^f - p_t) + \omega(p_t^b - p_t) \right]$$

Next, we need to obtain $(p_t^f - p_t)$ and $(p_t^b - p_t)$. Combining (B.2) and (B.4) leads to:

$$(B.6) \quad \begin{aligned} p_t^f - p_t &= (1-\delta\theta)E_t \sum_{s=0}^{\infty} \left\{ (\delta\theta)^s \left(\hat{m}_{c_{t+s}} - \frac{\alpha\varepsilon}{1-\alpha}(p_t^f - p_t) + \delta\theta \left(1 + \frac{\alpha\varepsilon}{1-\alpha} \right) \pi_{t,t+s+1} \right) \right\} \\ &= (1-\delta\theta)\zeta \sum_{s=0}^{\infty} (\delta\theta)^s E_t \{ \hat{m}_{c_{t+s}} \} + \sum_{s=1}^{\infty} (\delta\theta)^s E_t \{ \pi_{t+s} \}, \end{aligned}$$

where $\zeta = (1-\alpha)/(1+\alpha(\varepsilon-1))$.

Combining (A.19) and (B.3) yields:

$$(B.7) \quad p_t^b - p_t = \frac{1}{1-\theta} \pi_{t+1} - \pi_t.$$

In order to obtain the following expression for inflation, plugging (B.6) and (B.7) yields:

$$(B.8) \quad \pi_t = \frac{1-\theta}{\theta} \left[\omega \left(\frac{1}{1-\theta} \pi_{t-1} - \pi_t \right) + (1-\omega) \left((1-\delta\theta)\zeta \sum_{s=0}^{\infty} (\delta\theta)^s E_t \{ \hat{m}_{c_{t+s}} \} + \sum_{s=1}^{\infty} (\delta\theta)^s E_t \{ \pi_{t+s} \} \right) \right].$$

Finally, using some algebra, compact expression for inflation can be obtained:

$$(B.9) \quad \pi_t = \Psi_f \delta E_t \pi_{t+1} + \Psi_b \pi_{t-1} + \tilde{\lambda} \hat{m}_{c_t}.$$

where $\tilde{\lambda} = (1-\theta)(1-\delta\theta)(1-\omega)\zeta\phi^{-1}$, $\Psi_f = \theta\phi^{-1}$ and $\Psi_b = \omega\phi^{-1}$ with $\phi = \theta + \omega[1-\theta(1-\delta)]$.

Since $\hat{mc}_t = (\gamma + \gamma_n)y_t$, the hybrid Phillips curve expressed in terms of the output gap instead of real marginal cost is given by:

$$(B.10) \quad \pi_t = a_\pi \delta E_t \pi_{t+1} + (1 - a_\pi) \pi_{t-1} + \tilde{\kappa} y_t,$$

where $a_\pi = \Psi_f = \theta \phi^{-1}$, $1 - a_\pi = \Psi_b = \omega \phi^{-1}$, $\omega = \phi - \theta$ (if $\delta = 1$), $\tilde{\kappa} = \tilde{\lambda}(\gamma + \gamma_n)$ and $y_t = \hat{y}_t - \hat{y}_y^n$ (the output gap). For $a_\pi = 0.5$, we recover the original Fuhrer and Moore (1995) specification.

B.2. The Hybrid Dynamic IS Curve

Following Sahuc (2002), Carroll *et al.* (2000) and Fuhrer (2000), consumer's utility may be expressed as:

$$(B.11) \quad U_t(C_t, H_t) = \frac{-\gamma}{1-\gamma} (C_t - hH_t)^{\frac{1-\gamma}{-\gamma}},$$

where γ is the inverse of the intertemporal elasticity of substitution, C_t is the consumption level, H_t denotes the level of habit formation, and where h ($0 \leq h \leq 1$) measures the degree of habit formation. We assume that the consumer does not consider it as an argument to maximise his utility. In that sense, the habit level is external. We specify that the habit level (stock) equals the aggregate consumption level in the previous period, \bar{C}_{t-1} , *i.e.* $H_t = \bar{C}_{t-1}$ *ex-post*.

The representative household is infinitely lived and maximise his life utility, subject to the intertemporal budget constraint in Equation (A.2). Then, the Euler equation is given by:

$$(B.12) \quad 1 = E_t \left[\delta \frac{U'_t(C_{t+1}, H_{t+1})}{U'_t(C_t, H_t)} \frac{P_t}{P_{t+1}} (1 + i_t) \right]^{-1}$$

where δ is the time discount factor and P_t is the price level at time t . Equation (B.12) extends the usual first-order condition for consumption growth by taking into account the existence of external habit consumption.

Since $P_{t+1}/P_t = 1 + \pi_{t+1}$ and $U'_t(C_t, H_t) = (C_t - hH)^{-1/\gamma}$, Equation (B.12) can be written by:

$$(B.13) \quad E_t \left[\frac{1+i_t}{1+\pi_{t+1}} \right] = E_t \left[\delta \frac{(C_{t+1} - hH_{t+1})^{-1/\gamma}}{(C_t - hH_t)^{-1/\gamma}} \right]^{-1}$$

In linearising Equation (B.13) with Equation (B.11), we find a consumption equation with external habit equation:

$$(B.14) \quad c_t = \frac{1}{1+h} E_t c_{t+1} + \frac{h}{1+h} c_{t-1} - \frac{(1-h)\gamma}{(1+h)} (i_t - E_t \pi_{t+1} - r^*)$$

where c_t is the log of consumption at time t , and $r^* = -\ln(\delta)$.

When $h=0$, this equation reduces to the traditional forward-looking consumption. With the external habit formation, consumption depends on a weighted average of past and expected future consumption. Note that in this case the interest rate elasticity of consumption depends not only on the intertemporal elasticity of substitution of consumption γ , but also on the habit formation parameter, h .

From the market clearing condition for goods, $Y_t(z) = C_t(z)$ or $Y_t = C_t$, where Y_t is the aggregate output. Taking logs, $y_t = c_t$. Then, Equation (B.14) can be rewritten as:

$$(B.15) \quad y_t = \frac{1}{1+h} E_t y_{t+1} + \frac{h}{1+h} y_{t-1} - \frac{(1-h)\gamma}{(1+h)} (i_t - E_t \pi_{t+1})$$

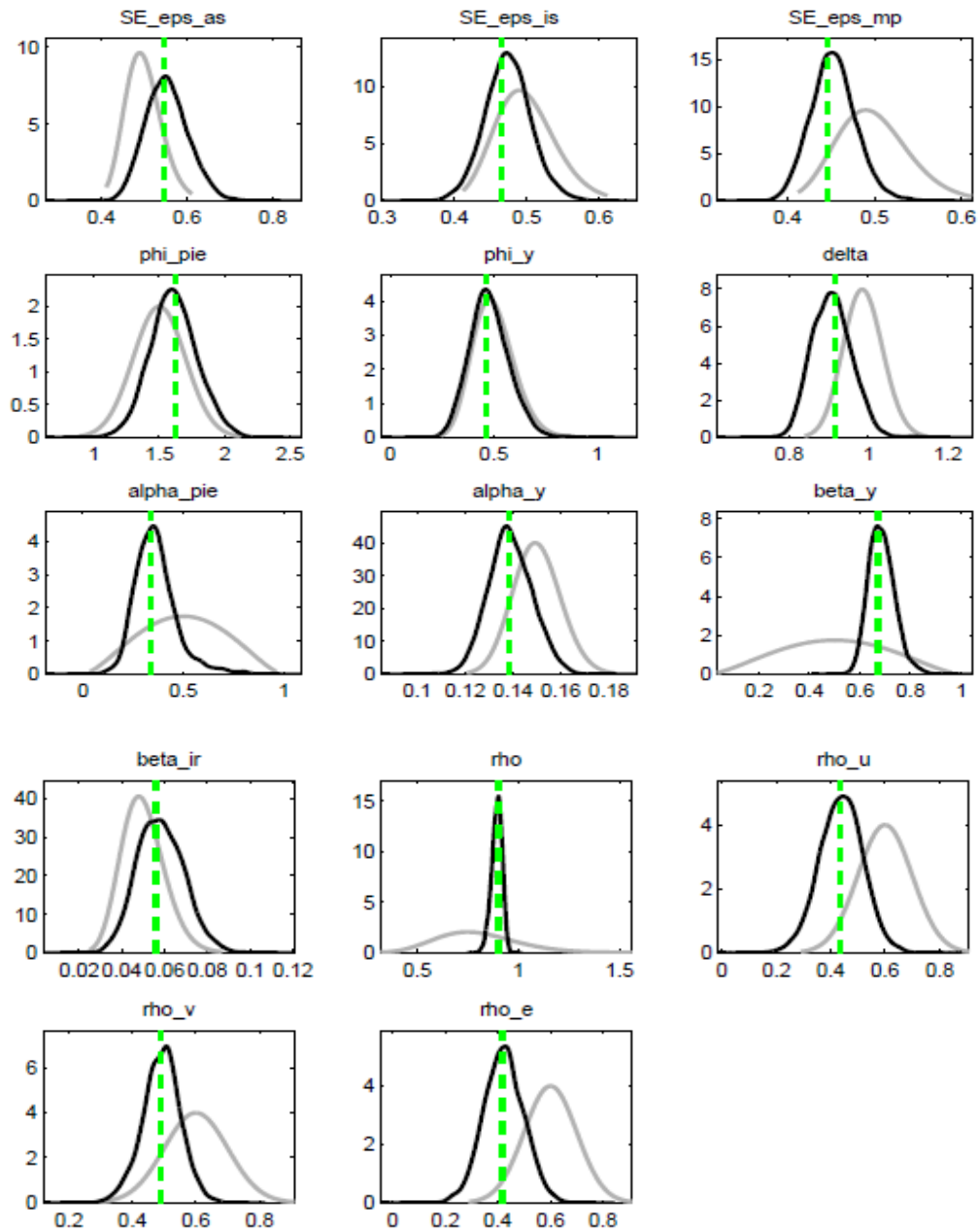
As can be seen in Equation (B.15), the monetary transmission mechanism is a function of the elasticity of substitution of consumption, γ , and the habit persistence parameter, h .

Finally, letting $\beta_y = \frac{1}{1+h}$ and $\beta_i = \frac{(1-h)\gamma}{1+h}$, we obtain the hybrid dynamic IS curve:

$$(B.16) \quad y_t = \beta_y E_t y_{t+1} + (1 - \beta_y) y_{t-1} - \beta_i (i_t - E_t \pi_{t+1})$$

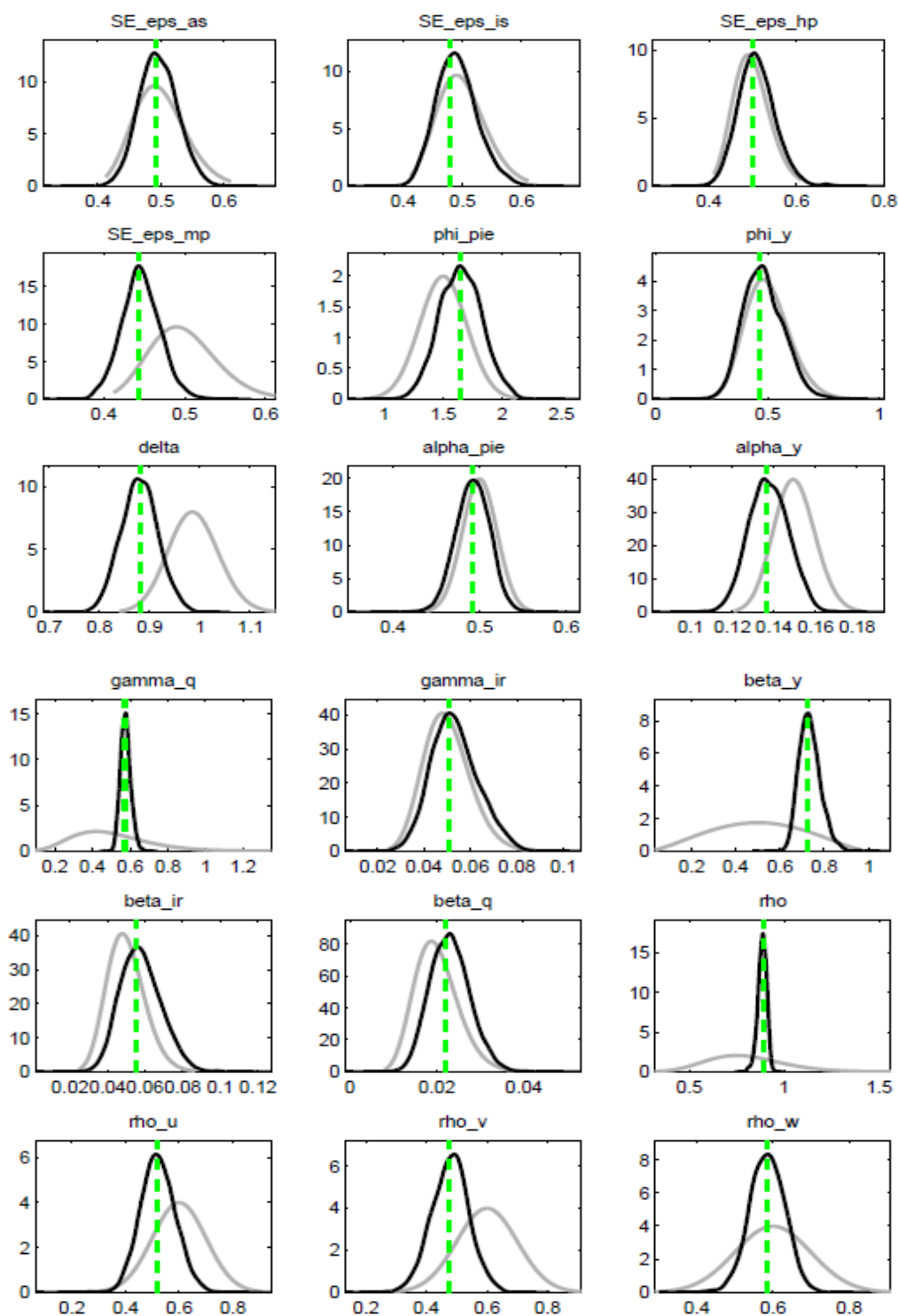
Appendix C. Parameter Distributions

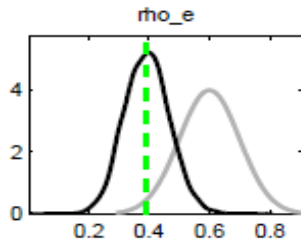
Figure C.6.1 Prior v.s. Posterior Distributions under the Baseline Model



Note: The posterior distributions (in the darker lines) of each parameter are contrasted against the given prior distributions.

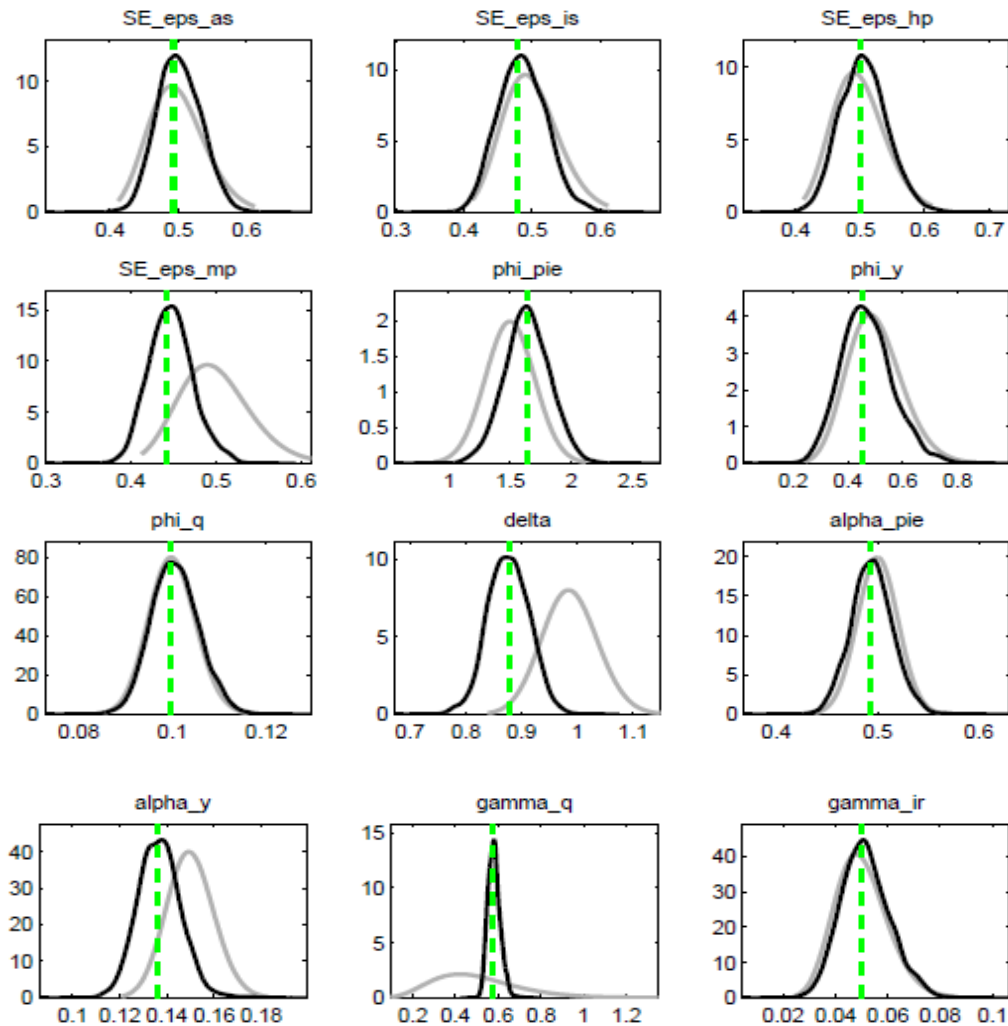
Figure C.6.2 Prior v.s. Posterior Distributions under the Alternative Model
(No consideration of house-price fluctuations)

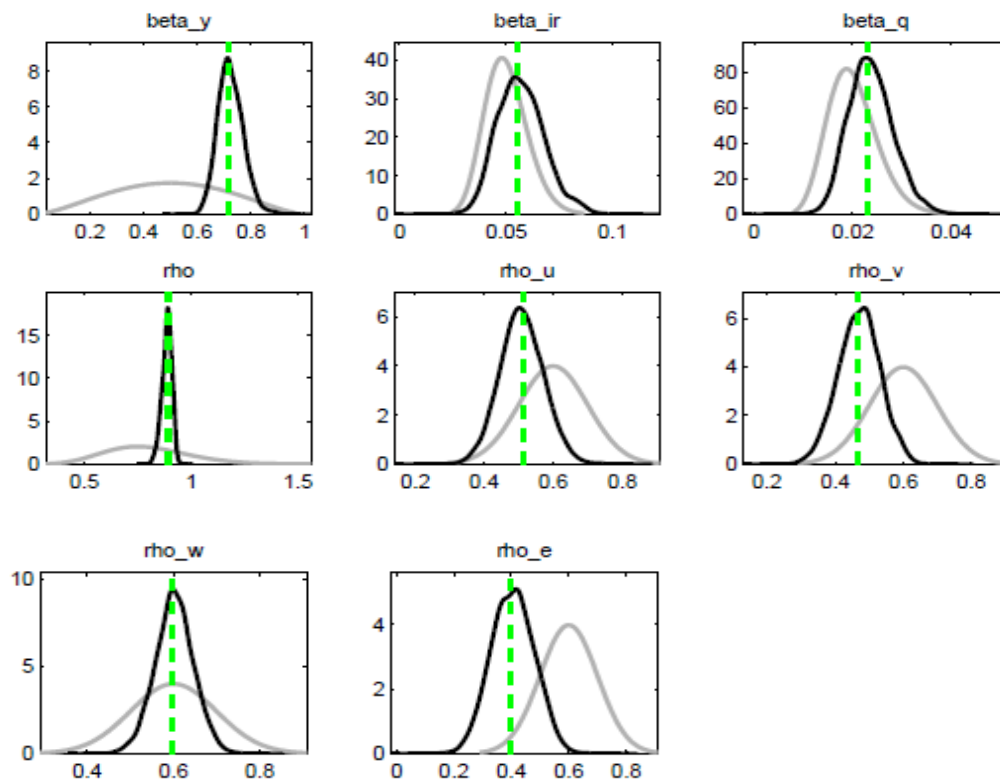




Note: The posterior distributions (in the darker lines) of each parameter are contrasted against the given prior distributions.

Figure C.6.3 Prior v.s. Posterior Distributions under the Alternative Model
(Consideration of house-price fluctuations)





Note: The posterior distributions (in the darker lines) of each parameter are contrasted against the given prior distributions.

Appendix D. Impulse Response Functions

Figure D.6.1 Impulse Responses of Variables to Shocks under the Baseline Model

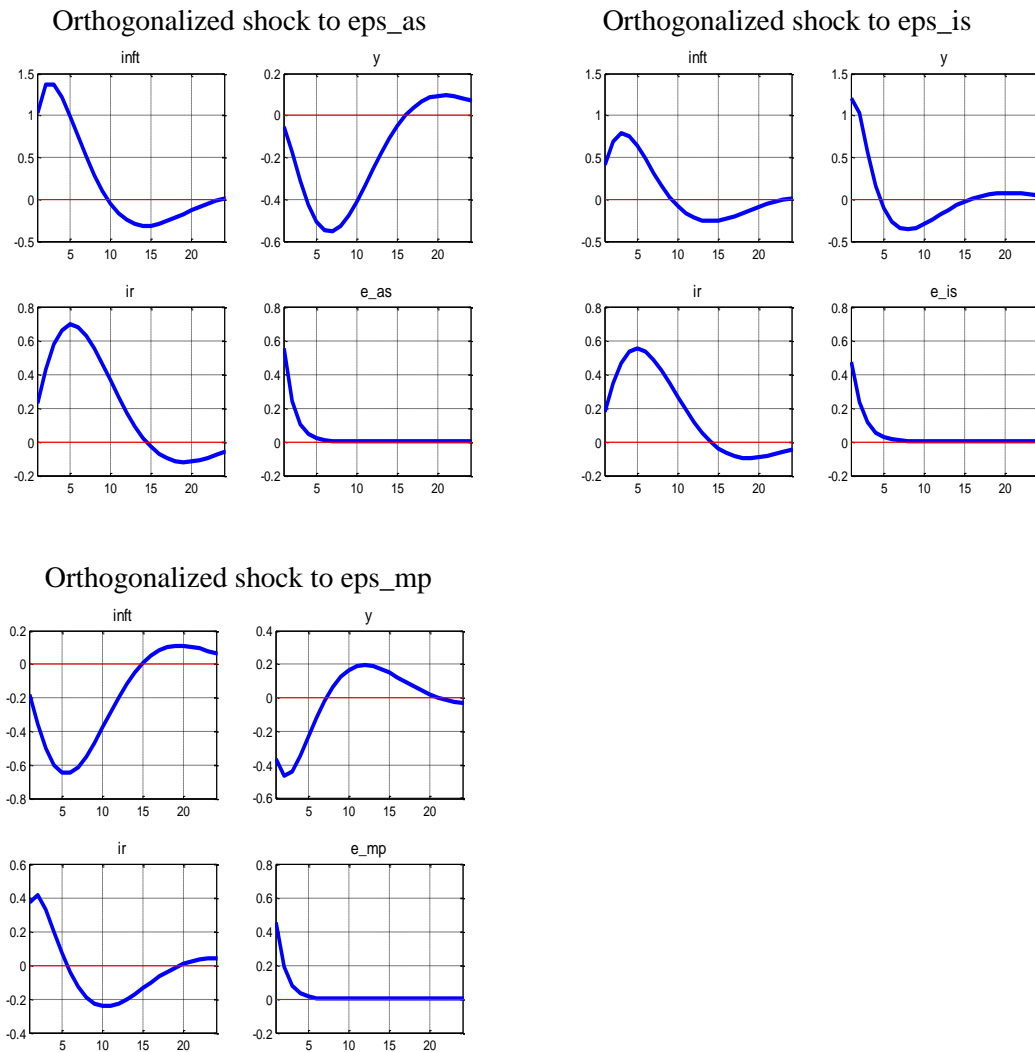


Figure D.6.2 Impulse Responses of Variables to Shocks under the Alternative Model that ignores House-price Fluctuations

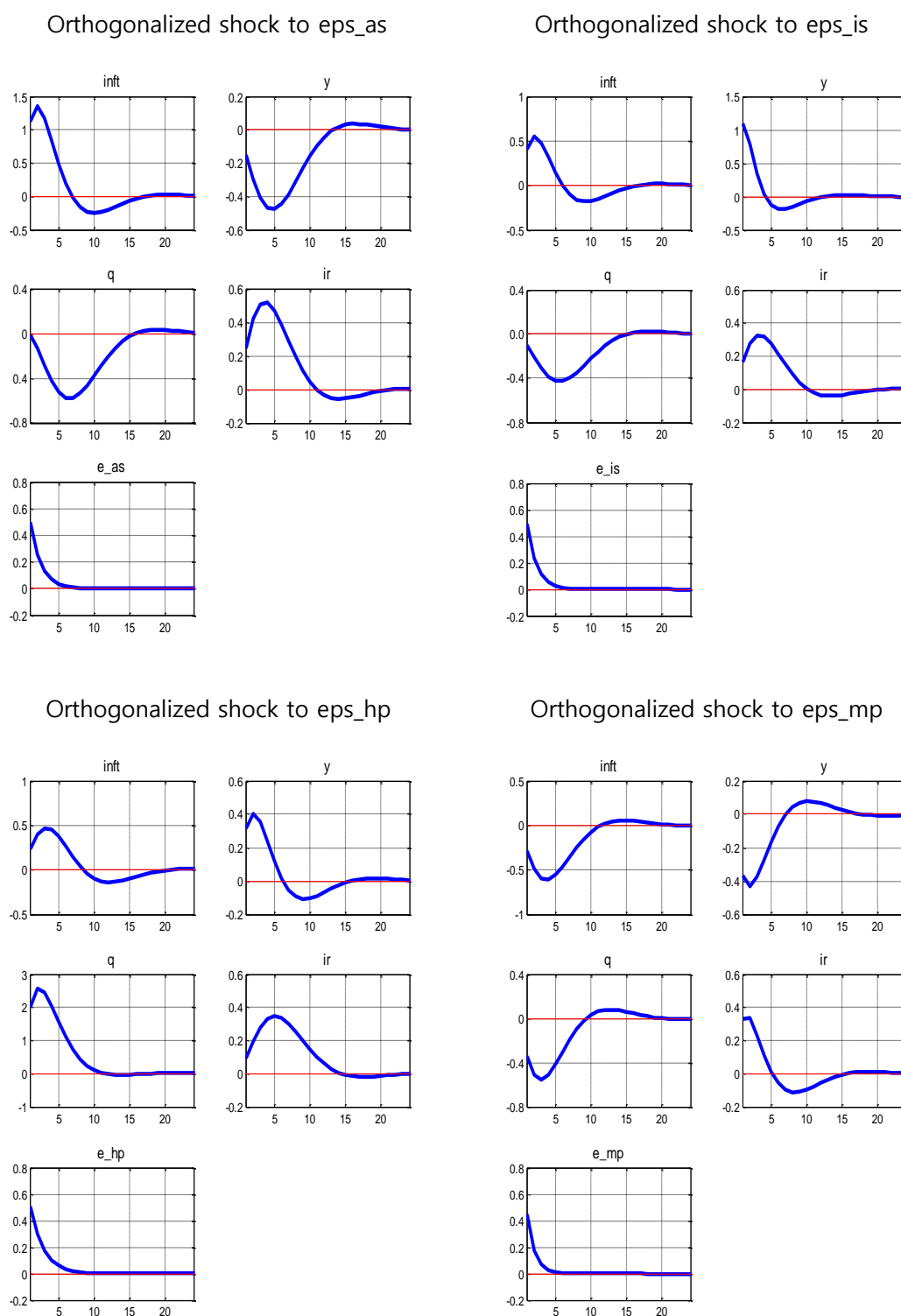
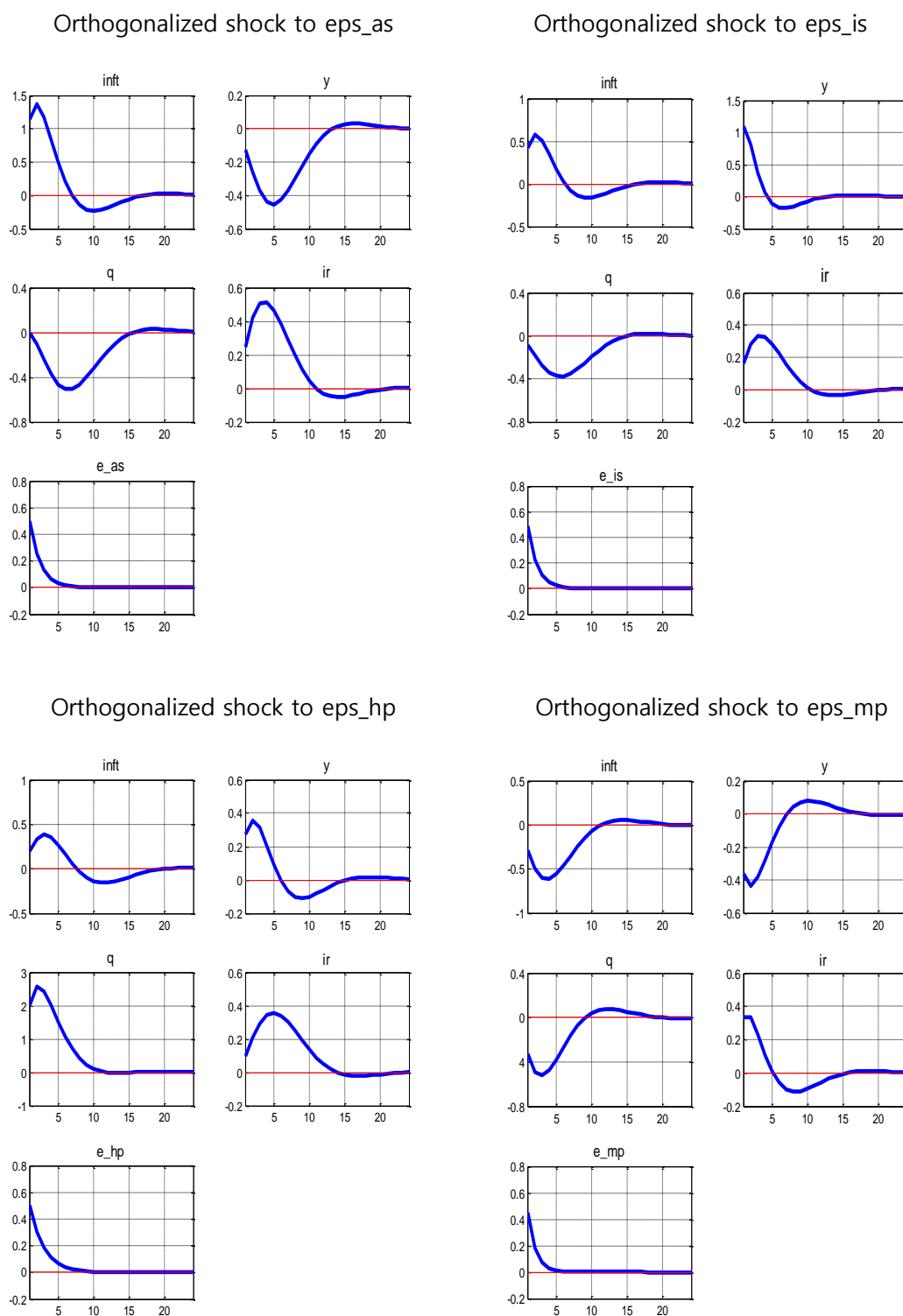


Figure D.6.3 Impulse Responses of Variables to Shocks under the Alternative Model that cares about House-price Fluctuations



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